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REPORT MDC E0484

PRE-SIMULATION REPORT

PHASE I

CREW INTERFACE DEFINITION STUDY

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY • EAST

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PHASE I

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1 OCTOBER 1971 **MDC E0484**

PRE-SIMULATION REPORT

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1. INTRODUCTION

This report contains the results of the timeline analysis of the Shuttle Orbiter missions which was conducted in Task 1 of the Phase I Crew Interface Definition Study and the requirements for the man-in-the-loop simulation study which is to be made.

In the initial part of this report, mission definitions and objectives are presented as they relate to various Shuttle Orbiter missions. The requirements for crew participation and the information required by the crew are discussed, and finally the rationale behind the display concept and calling procedures is given.

The remainder of the report presents the simulation objectives, the simulation mechanization, including a detailed presentation of the Display and Control Concept, the simulator test plan and the results.

2. LIST OF SYMBOLS

The following symbols and acronyms are used in this report unless noted otherwise:

ABE's	Air Breathing Engines
AC	Acquisition of the Heading Alignment Circle
ACPS	Attitude Control Propulsion System
A/D	Analog to Digital
ADI	Attitude Director Indicator
APU	Auxiliary Power Unit
BPI	Bits Per Inch
CDC	Control Data Corporation
CRT	Cathode Ray Tube
D/A	Digital to Analog
DEG	Degree
D&C	Display and Control
DME	Distance Measurement Equipment
ED	Energy Dissipation
FT	Feet
FA	Final Approach
°F	Degree Fahrenheit
FDI	Flight Director Indicator
FPS	Feet Per Second
GMT	Greenwich Mean Time
GN&C	Guidance, Navigation and Control
HA	Heading Alignment

HCR	High Crossrange
HFSS	High Fidelity Shuttle Simulator
HSI	Horizontal Situation Indicator
IDIIOM	Information Displays Incorporated Input Output Machine
ILS	Instrument Landing System
I/O	Input/Output
IRU	Inertial Reference Unit
KTS	Knots
L/D	Lift to Drag Ratio
LM	Lunar Module
MET	Mission Elapsed Time
NC	Nominal Catch-up
NM	Nautical Miles
OMS	Orbit Maneuver System
OOS	Orbit to Orbit Shuttle
P/L	Payload
PSF	Pounds per Square Foot
RCAH	Rate Command Attitude Hold
RCS	Reaction Control System
SEC	Second
VOR	Very High Frequency Omnidirectional Radio

3. TIMELINE ANALYSIS

A survey of several possible Shuttle missions was performed to determine the objectives of each and define common objectives between them. These results are tabulated in Figures 3-1 and 3-2 for the Orbiter and abort situations respectively. Analysis of the objectives for each mission indicates that any of the Orbiter missions can be accomplished using combinations of the following major flight operations:

- o Ascent Sequence
- o Rendezvous Sequence
- o Return Sequence
- o Orbit Operations
- o Payload Operations
- o Ferry Operations
- o Abort Operations

There are three sets of flight operations which are identified as sequences due to the manner in which they are normally performed. Each sequence incorporates a series of discrete phases with varying degrees of crew participation, however, once the crew tasks in each sequence are identified, the critical areas of crew participation required for any mission objective are also identified.

3.1 Mission Definitions and Objectives - The mission phases within each sequence and the objectives of each phase are summarized in the following paragraphs.

3.1.1 Ascent Sequence - The primary objective is insertion of the Orbiter into initial orbit (nominal 50 x 100 N.M.). It has four distinct phases:

- o Preflight Phase - Primary objective is to prepare the vehicle for flight. The computers are loaded, external alignment and calibration performed, final targeting performed, mission timeline verified

MISSION	DESCRIPTION	OBJECTIVES	FLIGHT OPERATIONS
SPACE STATION RESUPPLY	INSERT INTO ORBIT FOR COPLANAR RENDEZVOUS WITH SPACE STATION. PERFORM SEQUENCE OF MANEUVERS NECESSARY TO RENDEZVOUS WITH SPACE STATION BETWEEN 5 TO 24 HR. SPEND 1–7 DAYS AT SS EITHER DOCKED OR STATION KEEPING. RETURN TO SELECTED LANDING SITE	ORBIT INSERTION RENDEZVOUS WITH SPACE STATION TRANSFER CARGO AND/OR PERSONNEL RETURN TO LANDING SITE	PREFLIGHT ASCENT SEQUENCE RENDEZVOUS SEQUENCE PAYLOAD HANDLING RETURN SEQUENCE
PROPELLANT DELIVERY	INSERT INTO ORBIT FOR COPLANAR RENDEZVOUS WITH TARGET VEHICLE. PERFORM SEQUENCE OF MANEUVERS NECESSARY TO RENDEZVOUS WITH TARGET BETWEEN 5 TO 24 HR. TRANSFER PROPELLANT TO TARGET WHILE DOCKED OR BY TRANSFERRING PROPELLANT MODULE. RETURN TO SELECTED LANDING SITE	ORBIT INSERTION RENDEZVOUS WITH TARGET VEHICLE TRANSFER PROPELLANTS RETURN TO LANDING SITE	PREFLIGHT ASCENT SEQUENCE RENDEZVOUS SEQUENCE PAYLOAD HANDLING RETURN SEQUENCE
PROPULSIVE STAGE DELIVERY	INSERT INTO PRESELECTED ORBIT. TRANSFER TO DESIRED CIRCULAR ORBIT. DEPLOY P/L AND PERFORM REQUIRED CHECKOUT. RETURN TO SELECTED LANDING SITE	ORBIT INSERTION MANEUVER TO A PRESELECTED ORBIT DEPLOY PAYLOAD RETURN TO LANDING SITE	PREFLIGHT ASCENT SEQUENCE ON ORBIT SEQUENCE PAYLOAD HANDLING RETURN SEQUENCE
OOS DELIVERY AND RETRIEVE	INSERT INTO PRESELECTED ORBIT. TRANSFER TO DESIRED CIRCULAR ORBIT. DEPLOY OOS AND PERFORM REQUIRED CHECKOUT. REMAIN IN ORBIT AND WAIT FOR OOS RETURN. PERFORM SEQUENCE OF MANEUVERS NECESSARY TO RENDEZVOUS WITH RETURNED OOS. PICK UP OOS AND STOW IN CARGO BAY. RETURN TO SELECTED LANDING SITE	ORBIT INSERTION MANEUVER TO A PRESELECTED ORBIT DEPLOY OOS WAIT IN ORBIT RENDEZVOUS WITH OOS RETRIEVE OOS RETURN TO LANDING SITE	PREFLIGHT ASCENT SEQUENCE ON ORBIT SEQUENCE PAYLOAD HANDLING RENDEZVOUS SEQUENCE RETURN SEQUENCE
SATELLITE PLACEMENT	INSERT INTO PRESELECTED ORBIT. TRANSFER TO DESIRED CIRCULAR (OR ELLIPTICAL) ORBIT. DEPLOY SATELLITE(S) AND PERFORM REQUIRED CHECKOUT. IF REQUIRED, TRANSFER TO ANOTHER ORBIT, DEPLOY AND CHECKOUT MORE SATELLITE(S). RETURN TO SELECTED LANDING SITE	ORBIT INSERTION MANEUVER TO ONE OR MORE PRESELECTED ORBIT(S) RETURN TO LANDING SITE	PREFLIGHT ASCENT SEQUENCE ON ORBIT SEQUENCE PAYLOAD HANDLING RETURN SEQUENCE

ORBITER MISSIONS

Figure 3–1

MISSION	DESCRIPTION	OBJECTIVES	FLIGHT OPERATIONS
SATELLITE RETRIEVAL	INSERT INTO ORBIT FOR COPLANAR RENDEZVOUS WITH SATELLITE TO BE RETRIEVED. PERFORM SEQUENCE OF MANEUVERS NECESSARY TO RENDEZVOUS WITH TARGET. IF TARGET IS PASSIVE, SEQUENCES MUST ACCOUNT FOR SENSOR RANGE LIMITATIONS. RETRIEVE SATELLITE AND STOW IN CARGO BAY. IF ANOTHER SATELLITE IS TO BE RETRIEVED (PRIMARILY SAME i AND Ω), PERFORM SEQUENCE OF MANEUVERS NECESSARY TO RENDEZVOUS WITH IT. RETRIEVE SECOND SATELLITE AND STOW IN CARGO BAY. RETURN TO SELECTED LANDING SITE.	ORBIT INSERTION RENDEZVOUS WITH ONE (OR MORE IF WITHIN ORBITER ΔV CAPABILITY) ACTIVE OR PASSIVE (COOPERATIVE OR UNCOOPERATIVE TARGET) SATELLITES RETRIEVE SATELLITES RETURN TO LANDING SITE	PREFLIGHT ASCENT SEQUENCE RENDEZVOUS SEQUENCE PAYLOAD HANDLING RETURN SEQUENCE
SATELLITE PLACEMENT AND RETRIEVAL	INSERT INTO ORBIT COPLANAR RENDEZVOUS WITH SATELLITE TO BE RETRIEVED. TRANSFER TO ORBIT DESIRED FOR SATELLITE(S) TO BE DEPLOYED. DEPLOY SATELLITE(S) AND PERFORM REQUIRED CHECK-OUT. IF REQUIRED, TRANSFER TO ANOTHER ORBIT, DEPLOY AND CHECKOUT MORE SATELLITE(S). PERFORM SEQUENCE OF MANEUVERS NECESSARY TO RENDEZVOUS WITH SATELLITE TO BE RETRIEVED. THIS COULD BE EITHER CATCH-UP OR DWELL TYPE RENDEZVOUS DEPENDING ON RELATIVE ALTITUDES AND PHASING. RETRIEVE SATELLITE AND STOW IN CARGO BAY. RETURN TO SELECTED LANDING SITE	ORBIT INSERTION MANEUVER TO ONE OR MORE PRE-SELECTED ORBIT(S) COMPATIBLE WITH FINAL RENDEZVOUS WITH TARGET SATELLITE DEPLOY SATELLITE(S) RENDEZVOUS WITH TARGET SATELLITE RETRIEVE SATELLITE RETURN TO LANDING SITE	PREFLIGHT ASCENT SEQUENCE RENDEZVOUS SEQUENCE PAYLOAD HANDLING RETURN SEQUENCE
SHORT DURATION ORBITAL	INSERT INTO PRESELECTED ORBIT. TRANSFER TO DESIRED CIRCULAR (OR ELLIPTICAL) ORBIT. REMAIN IN THIS ORBIT FOR UP TO 30 DAYS. UNUSUAL ATTITUDES MAY BE REQUIRED. IF DESIRED, TRANSFER TO ANOTHER ORBIT FOR PART OF THE MISSION. IF ORBIT ALTITUDE IS LOW, ORBIT MAINTENANCE BURNS MAY BE REQUIRED. AT END OF MISSION, RETURN TO SELECTED LANDING SITE	ORBIT INSERTION MANEUVER TO DESIRED ORBIT MAINTAIN ORBIT UP TO 30 DAYS TRANSFER (IF DESIRED) TO ANOTHER ORBIT RETURN TO LANDING SITE	PREFLIGHT ASCENT SEQUENCE ON ORBIT SEQUENCE PAYLOAD HANDLING RETURN TO EARTH SEQUENCE
RESCUE	INSERT INTO ORBIT FOR COPLANAR RENDEZVOUS WITH SPACE STATION OR OTHER TARGET REQUIRING RESCUE. PERFORM SEQUENCE OF MANEUVERS NECESSARY TO RENDEZVOUS WITH TARGET IN SHORTEST POSSIBLE TIME (COULD BE CATCHUP OR DWELL). DEPLOY RESCUE MODULE AND/OR DOCK WITH TARGET AND PICK UP PERSONNEL. RETURN TO SELECTED LANDING SITE OR, RETREAT TO SAFE ORBIT, WAIT IN ORBIT AND THEN RETURN TO SELECTED LANDING SITE.	ORBIT INSERTION RENDEZVOUS WITH SPACE STATION OR OTHER TARGET IN SHORT TIME PICK UP PERSONNEL RETREAT TO SAFE ORBIT (OPTIONAL) RETURN TO LANDING SITE	PREFLIGHT ASCENT SEQUENCE RENDEZVOUS SEQUENCE PAYLOAD HANDLING ON ORBIT SEQUENCE RETURN TO EARTH SEQUENCE

ORBITER MISSIONS (Continued)

Figure 3–1

INTACT ABORT MODE	DESCRIPTION	OBJECTIVES	FLIGHT OPERATIONS
LAUNCH ABORT MODE I (ORBITER FIRST REV RETURN)	BOOSTER ENGINE FAILURES PRECLUDE CONTINUING NOMINAL MISSION, BUT ENOUGH REMAIN TO ALLOW ORBITER INSERTION INTO A ONE REVOLUTION RETURN ORBIT. BURN REMAINING BOOSTER ENGINES TO PROPELLANT DEPLETION, STAGE, AND BURN ORBITER MAIN AND OMS ENGINES TO INSERT INTO ONCE AROUND ORBIT. RETURN TO LAUNCH/LANDING SITE	LOW DYNAMIC PRESSURE AT SEPARATION NOMINAL BOOSTER RETURN ONE REVOLUTION ORBITER RETURN TO LAUNCH/LANDING SITE	PRELAUNCH ASCENT SEQUENCE ABORT SEQUENCE RETURN SEQUENCE BOOSTER RETURN SEQUENCE
LAUNCH ABORT MODE II (ORBITER RETURN TO LAUNCH/LANDING SITE	BOOSTER ENGINE FAILURES PRECLUDE NOMINAL MISSION OR ONCE AROUND ORBITER RETURN. BURN REMAINING BOOSTER ENGINES TO PROPELLANT DEPLETION, STAGE AND BURN ORBITER ENGINES TO INSERT INTO A RETURN TO LAUNCH/LANDING SITE TRAJECTORY	LOW DYNAMIC PRESSURE AT SEPARATION NOMINAL BOOSTER RETURN ORBITER DIRECT RETURN TO LAUNCH/LANDING SITE	PRELAUNCH ASCENT SEQUENCE ABORT SEQUENCE RETURN SEQUENCE BOOSTER RETURN SEQUENCE
LAUNCH ABORT MODE III (ORBITER ENGINE FAILURE)	NOMINAL BOOSTER BURN AND SEPARATION. FAILURE OF ONE ORBITER ENGINE PRECLUDE CONTINUING NOMINAL MISSION. OMS ENGINES BURNED IN PARALLEL WITH REMAINING MAIN ENGINE TO INSERT ORBITER INTO ONCE AROUND ORBIT. RETURN TO LAUNCH/LANDING SITE	ONE REVOLUTION ORBITER RETURN TO LAUNCH/LANDING SITE	PRELAUNCH ASCENT SEQUENCE ABORT SEQUENCE RETURN SEQUENCE BOOSTER RETURN SEQUENCE
ON-ORBIT ABORT	FAILURE OF ORBITER SUBSYSTEM PRECLUDES CONTINUATION OF NOMINAL MISSION. ORBITER WAITS IN ORBIT UNTIL RETURN CAN BE MADE. RETURN TO SELECTED LANDING SITE	RETURN TO SELECTED LANDING SITE	RETURN SEQUENCE
DESCENT/RETURN ABORTS	NON-CATASTROPHIC SUBSYSTEM FAILURE UNLIKELY. WEATHER OR LANDING SITE PROBLEMS REQUIRE DIVERSION TO ALTERNATE SITE	RETURN TO ALTERNATE SITE WITHIN LANDING FOOTPRINT BOOSTER COULD DIVERT AND CRUISE TO ALTERNATE SITE	RETURN SEQUENCE BOOSTER RETURN SEQUENCE
LANDING GO-AROUND ABORTS	APPLICABLE TO BOOSTER AND ORBITER WITH ABES IN. VEHICLE MISSES INITIAL APPROACH, ADDS ABES POWER TO GO-AROUND FOR ANOTHER TRY	SECOND TRY AT FINAL APPROACH AND LANDING	ABORT SEQUENCE

ABORT MODES

Figure 3-2

and the vehicle configured for launch.

- Mated Flight Phase - Primary objective is for the Booster to carry the Orbiter to the desired separation conditions. The Booster guidance, navigation, and control (GNC) functions are primary during this phase. The Orbiter GNC functions provides the contingency backup and monitor capability.
- Separation Phase - Primary objective is to separate the Booster and Orbiter Flight. The Booster separation command is primary and the Orbiter provides backup separation command capability.
- Orbit Insertion Phase - Primary objective is for the Orbiter to continue its flight and insert into orbit. Orbiter main engines provide the primary thrust. The Orbiter GNC function is primary.

3.1.2 Rendezvous Sequence - The primary objective is to fly from insertion to a co-orbit condition with another orbital vehicle. A particular sequence may be influenced by other objectives, (such as satellite deployments) but until the rendezvous is accomplished, it is the primary mission objective. A rendezvous sequence is divided into periods of coasting flight and powered flight. During coast, the Orbiter is non-thrusting. Navigation operations are performed during coast periods using horizon sensor measurements initially and line-of-sight range and angle measurements later in the rendezvous mode. The platform alignments are performed and tested against sightings and the spacecraft is maneuvered to desired attitudes for performing the next maneuver. During long coasting periods, the guidance system may be powered down to a standby mode. During powered flight, the Orbiter is thrusting with the OMS engines or ACPS engines. Thrust vector control and attitude control are provided by the orbital powered flight guidance and control autopilot. The navigation incorporates acceleration measurement during powered flight. The rendezvous sequence has four distinct phases:

- Orbital Adjustment Phase - Primary objective is to correct the phasing with the rendezvous target. The catch-up (or dwell if rendezvous is from above) can vary between zero to 17 or 18 hours, depending on the initial phasing at insertion. Several maneuvers can be made, usually horizontal in-plane (or NC type). The purpose of these maneuvers is to place the Orbiter in a favorable position with respect to the target for performing the relative phase maneuvers. Navigation is corrected using horizon sensor measurements.
- Coelliptic Phase - Primary objective is to place the Orbiter at the desired terminal condition prior to initiating an intercept trajectory. Navigation is now corrected with relative measurements. Maneuvers during this phase are corrective combinations which adjust the orbit to meet the lighting and relative motion requirements in the terminal phase and to remove accumulated GNC errors.
- Terminal Phase - Primary objective is to place the Orbitor on an intercept trajectory with the target and to perform braking to achieve a station keeping condition. Navigation is corrected with relative measurements and maneuvers are generally relative to the line-of-sight.
- Station Keeping Phase - Primary objective is to maintain a relative position in the near vicinity of the target vehicle.

3.1.3 Return Sequence - The primary objective is to return the Orbiter from orbit to a preselected landing site. The sequence includes orbital coasting and powered flight, as well as hypersonic, supersonic, and subsonic aerodynamic flight. The sequence has four distinct phases:

- Deorbit Phase - Primary objective is to select a landing site and perform the deorbit maneuver. Platform alignment and navigation are necessary and therefore included in this phase.
- Entry Phase - The initial objective is to prepare for entry interface. Final platform alignments and navigation are performed. The Orbiter is configured for entry and rotated to the entry attitude. The next objective is controlling the Orbiter angle of attack and bank angle to 'fly out' the targeted crossrange and downrange while avoiding temperature, g-load and skip out constraints. A typical entry is characterized by the initially high constant angle of attack and large bank angle followed by a pullout where bank angle (and angle of attack if necessary) are modulated to avoid heating on temperature constraints. During this period, all optics hatches are closed and radio blackout prevents measurements for correcting the propogation of nagivation errors.
- Terminal Area Phase - Primary objective is to control the Orbiter energy level for the desired final approach conditions. Included in this phase is the transition maneuver where the vehicle is maneuvered from the backside to the frontside of the L/D (lift over drag) curve. After transition, energy dissaption is controlled by flying along a preselected path from which the vehicle can be steered easily onto final approach. Navigation during this phase is via ground based radio aids such as VOR and DME.
- Final Approach Phase - Primary objective is to control the vehicle and guide it to touchdown. Final approach is initiated along a steep glide slope (nominal 13 degrees) until intercept of the

conventional ILS glide slope at approximately 800 ft. The ILS glide slope is then flown to touchdown.

3.1.4 Orbit Operations - The primary objective is to provide flexibility for performing orbital changes not necessarily connected with rendezvous. The particular operations for a mission depend on the desired final orbit. Thus, a sequence could be generated which would range from one or two Hohmann transfers if orbit size and shape are the only controlling parameters to a "phantom" rendezvous sequence if perigee location and time of perigee passage or mode crossing are also to be controlled. As with the rendezvous sequence, a sequence of orbital operations would be divided into periods of coasting flight and powered flight. Based on the various mission objectives, the orbit sequence can have the following maneuvers:

- Hohmann Transfer Maneuvers - Primary objective is to perform a series of horizontal in-plane maneuvers (at apogee or perigee if orbit is elliptical) designed to satisfy the final orbital parameters. By controlling lift-off time and launch azimuth, many missions can be accomplished entirely within this capability.
- Out-of-Plane Maneuvers - Primary objective of this maneuver is to adjust in-plane and/or out-of-plane dispersions with one corrective maneuver. Again, because of high ΔV requirements, this phase is avoided if possible except for small adjustments.

3.1.5 Payload Operations - The primary objective is to guide and control the Orbiter as necessary to meet payload handling requirements. Depending on the mission any or all of the following maneuvers could be encountered:

- Docking - Primary objective is to move from a station keeping mode to a docking condition with the rendezvous target. During docking, relative attitude and rates as well as range and range rates are controlled parameters. Docking is performed manually.

- Undocking - Primary objective is to move from a docked condition.
- Payload Deploy/Retrieve - Primary objective is to maintain desired attitude and perform necessary maneuvers while deploying, retrieving or otherwise handling payloads.

3.1.6 Ferry Operations - The primary objective to fly the vehicle from one airport to another. The operations are similar to those involved in flying conventional aircraft. There are four aspects:

- Preflight - Primary objective is to plan the flight. The cruise route is selected and the vehicle checked out for flight.
- Take-off - Primary objective is to get airborne and configured for cruise. This is a manual operation.
- Cruise - Primary objective is to guide the vehicle to the terminal airport area. Navigation is accomplished using VOR/DME radio aids and powered flight inertial navigation. Autopilot modes include altitude hold, heading hold, VOR mode and an area navigation mode.
- Descent and Landing - Primary objective is to land the vehicle at the terminal airport.

3.1.7 Abort Operations - The primary objective is to interrupt the normal sequence where the abort situation occurs and carry the abort operation to a point where a nominal sequence can be re-entered. Because on-orbit or descent/return aborts can be handled in the nominal return sequence, abort operations are primarily for ascent aborts. Abort operations are therefore identified with the following:

- Mated Booster - Primary objective is to steer the Booster to the best burnout condition for either first rev return or flyback return.

- Orbiter Insertion - Primary objective is for the Orbiter to insert into a once around return orbit.
- Orbiter Flyback - Primary objective is for the Orbiter to return to the launch site.

3.2 Requirements For Crew Participation - The high degree of autonomy implicit in the Shuttle design, requires a simplified and well organized method of on-board mission control and subsystem management. The on-board system will perform routine or pre-selectable functions automatically, leaving the crew free to provide the decision making functions and to perform certain special mechanical tasks. This places the crew in the role of system supervisor, sequence initiator and providing hardware/software backup. Crew participation can be subdivided into several functional areas:

- Evaluations of mission sequence and mission status in real-time flight conditions.
- Specification of certain data, constraints or performance options.
- Initiation of mission sequences and unique operations with the flight system and control of the mode of performance.
- Evaluation of the status of the mission and the capability of the flight system to perform
- Determination of what flight operation to perform and the manner it will be executed
- Initiation and discontinuation of flight operations, phases and tasks which are pertinent to the control of the flight system and the performance of the mission

- o Selection of the subsystem interface with sensor components and the modes of subsystem operation
- o Recognition of pattern of degraded performance and logical fault isolation.

The data in Figure 3.2-1 reveals the types of information required by the crew.

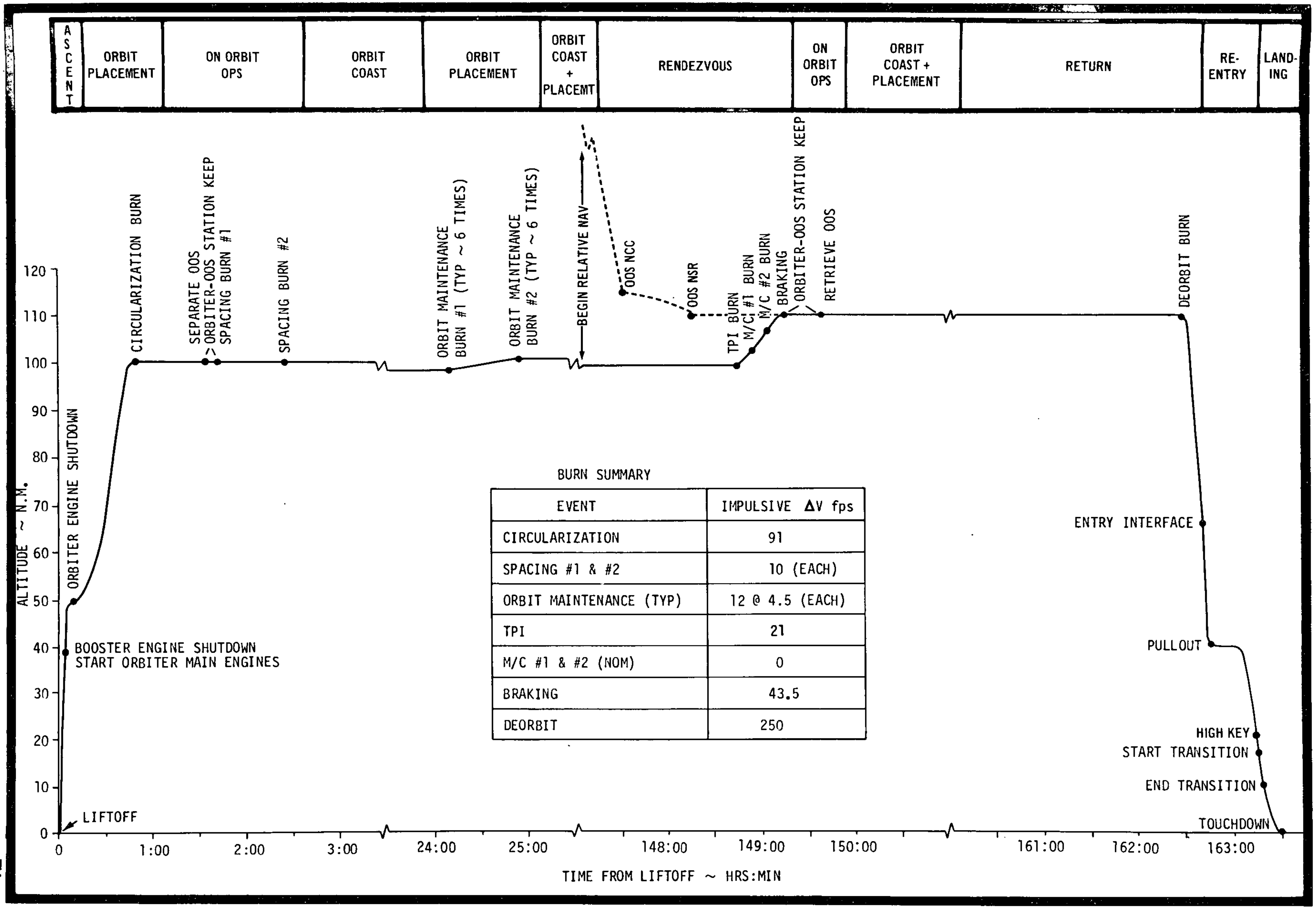
As an aid in defining crew tasks, two types of timelines have been developed. The first is a functional event timeline. This timeline details major and minor events, defines the functions to be performed during a mission and gives an indication of the time available to perform the various functions. An easterly launch orbit to orbit Shuttle (OOS) delivery and retrieval was chosen for illustration since it includes all sequences of operation except abort and ferry. The mission profile is shown in Figure 3.2-2 and the functional event timeline is presented in Figure 3.2-3. The second type of timeline is the crew/computer task timeline. This timeline details, on a "semi-procedural" level, specific crew and corresponding computer tasks and the information required to perform each task. Figure 3.2-4 presents the crew/computer task timeline for the Return Sequence. This sequence is probably the most demanding and provides a variety of operational phases.

Guidance, navigation and control parameter requirements have been defined for the Shuttle missions. Figure 3.2-5 illustrates the results of this effort. The pertinent parameters, the applicable flight sequence and phase and the required level of crew participation are indicated.

INFORMATION TYPE	TYPICAL INFORMATION REQUIRED BY CREW
NAVIGATION • WHERE ARE WE? • WHERE ARE WE GOING? • HOW WELL DO WE KNOW THIS?	CURRENT AND PROJECTED TRAJECTORY CURRENT ORBITAL OSCULATING ELEMENTS CURRENT AND PROJECTED STATE WITH RESPECT TO: • INSERTION BURNOUT CONDITIONS • A MOVING TARGET (SATELLITE) • DESIRED ORBITAL PARAMETERS • THE LANDING SITE • GROUND NAVAIDS OR LANDMARKS ESTIMATED AND PROJECTED ERRORS IN THE STATE
GUIDANCE • WHERE DO WE WANT TO GO? • HOW DO WE GET THERE?	LOCATION, STATE OR EPHEMERIS OF DESIRED TARGET NUMBER AND TYPES OF MANEUVERS REQUIRED TO REACH TARGET TIME OF AND ΔV REQUIRED FOR EACH MANEUVER DESIRED TRAJECTORY OR CRUISE ROUTE GUIDANCE PARAMETERS FOR CONTROLLING EACH PHASE OF FLIGHT • ALTITUDE – VELOCITY PROFILES • RELATIVE TRAJECTORY PROFILES • BRAKING GATES • LANDING FOOTPRINT • GROUND TRACKS • ENERGY – RANGE PROFILES • FINAL APPROACH PROFILES
CONTROL • HOW DO WE IMPLEMENT GUIDANCE? • WHAT ATTITUDES ARE DESIRED?	CURRENT VEHICLE ATTITUDE AND ATTITUDE RATES COMMANDED ATTITUDES AND ERRORS MEASURED ΔV AND ΔV TO GO ANGULAR DISPLACEMENTS (BODY AXIS – VELOCITY VECTOR) AUTO AND MANUAL CONTROL MODES
COMMUNICATIONS • WHO OR WHAT CAN WE "TALK" TO? • HOW DO WE DO IT?	GROUND STATION OR TARGET SATELLITE VISIBILITY & VIEW PERIODS TRANSMIT AND RECEIVE FREQUENCIES ANTENNA POINTING REQUIREMENTS
TIME • HOW LONG SINCE A PREVIOUS EVENT? • HOW LONG TILL SOME FUTURE EVENT? • HOW MUCH TIME LEFT FOR THE CURRENT EVENT?	GROUND ELAPSED TIME (GET) FROM LIFTOFF OR TAKEOFF GET FOR ENGINE START & STOP GET FOR ATTITUDE CHANGES TIME REMAINING (Δt) TO START OR END OF EVENT OR PHASE ESTIMATED TIME OF ARRIVAL (ETA)
CONSTRAINTS • WHAT CONDITIONS ARE TO BE AVOIDED?	TRAJECTORY CONSTRAINTS TIME CONSTRAINTS VEHICLE OR SUBSYSTEM LIMITATIONS
SUBSYSTEM OPERATION • ARE THE SUBSYSTEMS I'M USING OR ABOUT TO USE CONFIGURED PROPERLY? • AM I FOLLOWING THE PROPER PROCEDURES? • ARE THE SUBSYSTEMS I'M USING PERFORMING AS EXPECTED? • IS MY SOFTWARE PERFORMING AS EXPECTED?	VEHICLE AND SUBSYSTEM CONFIGURATION DATA SUBSYSTEM PERFORMANCE DATA HANDBOOK/PROCEDURES INFORMATION OUTPUTS OF ALTERNATE SOFTWARE
SUBSYSTEM STATUS • WHAT SUBSYSTEMS ARE IN USE? • HAVE ANY LRU'S OR SUBSYSTEMS REDUNDANT UNITS FAILED OR INDICATING PENDING FAILURES? • WHAT CONSUMABLES REMAIN AND ARE THEY SUFFICIENT?	CAUTION AND WARNING INDICATORS FOR CRITICAL ITEMS LRU AND SUBSYSTEM STATUS DATA CONSUMABLES REMAINING AND PREDICTED USAGE NECESSARY DEDICATED DISPLAYS OF TEMPERATURES, PRESSURES, VOLTAGES, ETC.
PLANNING • CAN MY CURRENT MISSION OBJECTIVES BE MET? • ARE THERE ANY ALTERNATIVES? • IS MY TIMELINE OK?	CURRENT STATUS OF TRAJECTORY & VEHICLE STATUS WITH RESPECT TO NOMINAL TIMELINE ALTERNATE SEQUENCES TO MEET MISSION OBJECTIVES ALTERNATE MISSION OBJECTIVES

CREW INFORMATION REQUIREMENT

Figure 3.2–1



EVENT	IMPULSIVE ΔV fps
CIRCULARIZATION	91
SPACING #1 & #2	10 (EACH)
ORBIT MAINTENANCE (TYP)	12 @ 4.5 (EACH)
TPI	21
M/C #1 & #2 (NOM)	0
BRAKING	43.5
DEORBIT	250

EASTERLY DESIGN MISSION
MISSION PROFILE

Figure 3.2–2

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
Prelaunch	o Start APU o Initialize Powered Flight Navigation o Initialize Launch Control System Monitor o Initialize Timing Functions o Launch Configuration Checklist o Transfer from External to Internal Power		
0	LIFT OFF o Perform System Monitoring o Monitor Launch Phase Guidance o Perform Powered Flight Navigation o Perform Abort Monitor		
:03:17	Stage o Booster Engine Cut-off o Altitude = 238,740 feet (39.29 NM) o ΔV = 15,247 FPS o Separation o Orbiter Engine Ignition o Continue Powered Flight Navigation o Monitor Insertion Phase Guidance o Monitor Systems Status		
:06:41	Orbiter Shutdown o Burn Time = 3.23 minutes o ΔV - TBD o Orbit = 50 x 100 NM o Initiate Inertial Hold o Continue Powered Flight Navigation		
:08	Begin Dumping Residual Main Propellant		
:09:40	Complete Dump of Main Propellant		
:10	Commence Velocity Residual Trim		
:12	Trim Complete		
:12	Terminate Powered Flight Navigation		

FUNCTIONAL EVENT TIMELINE
EASTERLY DESIGN MISSION

Figure 3.2-3

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
:12	Maneuver to Orbiter +X on Local Horizontal Attitude (0,0,0)		
:13	Maneuver Complete o Initiate Orb Rate o Open Optics Hatch o Initiate Orbit Navigation o Post Insertion Checklist o Initiate Automatic IRU alignments		
:13	Open P/L Bay Door and Deploy ECS Radiator		
:14	Radiator Deployed		
:14	Shutdown APU		
:14	One Crew man to Docking Station		
:16	Check Restrained OOS		
:18	OOS Check Completed	:18	OOS NO-GO o Possibly Safe OOS o Possibly Deorbit and Re-enter at Early Opportunity
:19	Crew man to Cockpit from Docking Station		
:21	System Status Checks		
:23	Check Complete		
:25	IRU Align		
:30	IRU Align Complete		
:48	Trim Attitude for Circularization Burn (Burn in Orb Rate)		
:49	Initiate Powered Flight Navigation o System Preburn Checklist		
:49:42	Commence Circularization Burn o +X Orbiter Thrust o 91 FPS Total o Terminate Powered Flight Navigation after Burn o Orbit = 100 x 100 NM		
:50:12	Impulsive Circularization Burn Time		

FUNCTIONAL EVENT TIMELINE (Continued)
EASTERLY DESIGN MISSION

Figure 3.2-3

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
:50:41	Burn Complete		
:52	Trim Orb Rate		
1:03	Establish Voice/Data Link with Ground		
1:05	System Status Checks		
1:07	Check Complete		
1:07	IRU Align		
1:12	IRU Align Complete		
1:12	One Crew man to Docking Station		
1:14	Check Restrained OOS		
1:16	Check Completed	1:16	OOS NO-GO (See :18)
1:16	Maneuver to Separation Attitude (BEF)		
1:19	Maneuver Complete o Maintain Orb Rate		
1:19	Release OOS Tie Downs		
1:21	Extend OOS (Rotate OOS 90°)		
1:24	OOS Extended		
1:24	Rigidize Docking Mechanism		
1:26	Docking Mechanism Rigidized		
1:26	Check Extended OOS o Visual o Data Link		
1:28	Extended OOS Check Complete	1:28	OOS NO-GO
1:28	Deploy Command Antenna	1:28	Possibly Safe OOS
1:29	Test Antenna Gimbal and RF	1:30	Stow OOS
1:30	Antenna Deployed	1:30	Relax Docking Mechanism

FUNCTIONAL EVENT TIMELINE (Continued)
EASTERLY DESIGN MISSION

Figure 3.2–3

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
1:30	IRU Align	1:31	Rotate OOS 90°
1:34	IRU Align Complete	1:33	Secure OOS Tie Downs o Perform "On Orbit Functions" (See 3:50) Once Each 90 Minutes o Skip to 162:16 or Possibly Deorbit and Re-enter at Early Opportunity
1:34	Separate OOS Commence Station Keeping at Safe Distance		
1:36	OOS Activation eg o OOS Orientation o OOS Attitude Hold o OOS Deploy Antenna, Etc.		
1:36	Check Separated OOS o Visual o Data Link		
1:39	Check Completed	1:39	OOS NO-GO
1:39	Initiate Powered Flight Navigation o System Preburn Checklist	1:39	Command OOS Make Ready
		1:41	Verify OOS Make Ready Successful If not Successful o Possibly Space from OOS and Destroy OOS
1:40	OOS-Orbiter Spacing Burn o 10 fps Radial Down o 10 sec Burn Time o +Z Orbiter Thrust o Terminate Powered Flight Navigation o Monitor OOS and P/L during spacing	1:41	Visual Inspection of OOS
		1:43	Engage and Latch Docking Ring
1:42	Relax Docking Mechanism	1:43	Safe OOS
1:43	Stow Docking Mechanism	1:45	Verify OOS Safe
1:53	OOS Ignition and Transfer to Mission Orbit	1:46	Stow OOS
		1:46	Relax Docking Mechanism
1:55	Maneuver to SEF o Establish Orb Rate	1:47	Rotate OOS 90°
2:13	System Status Check	1:49	Secure OOS Tie Downs Perform "On Orbit Functions" (See 3:50) Once Each 90 Minutes
2:15	Checks Complete		
2:15	IRU Align		SKIP to 162:16 or Possibly Deorbit and Re-enter at Early Opportunity
2:20	IRU Align Complete		

FUNCTIONAL EVENT TIMELINE (Continued)
EASTERLY DESIGN MISSION

Figure 3.2–3

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
2:24	Initiate Powered Flight Navigation o System Preburn Checklist		
2:25	Terminate Spacing Burn o 10 fps Radial Up o ≈10 Second Burn Time o Terminate Powered Flight Navigation after Burn o Burn ΔV in Components		
3:50	Perform "On Orbit Functions" (Once Each 90 Minutes Except during "Sleep" mode) +0:00 System Status Checks +0:02 Checks Complete +0:02 IRU Align +0:07 IRU Align Complete +0.07 Trim Orb Rate		
09:00	Go to "Sleep" mode once each day +0:00 Begin "Sleep" Mode (Typical) +9:00 End "Sleep" Mode (Typical)		
24:00	Perform Orbit Maintenance Burns Once per Day +0:00 Target Orbit Maintenance Burns o Initial Orbit 98.5 NM Circular o First Burn raises Apogee to 101 NM o Second Burn One-Half Orbit Later Circularizes Orbit at 101 NM +0:05 System Preburn Checklist +0:07 Checklist Complete +0:08 Trim Attitude for Orbit Maintenance Burn No. 1 o Burn in Orb Rate o Initiate Powered Flight Navigation +0:10 Commence Orbit Maintenance Burn No. 1 o +X Orbiter Thrust o $\Delta V \approx$ 4.5 FPS o ≈12 Sec. Burn Time o Orbit = 101 x 98.5 NM o Terminate Powered Flight Navigation after Burn		

FUNCTIONAL EVENT TIMELINE (Continued)
EASTERLY DESIGN MISSION

Figure 3.2–3

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
	+0:11 Trim Orb Rate +0:45 Target Orbit Maintenance Burn No. 2 o Update Targeting to Account for Burn No. 1 Parameters		
	+0:49 System Preburn Checklist +0:51 Checklist Complete +0:52 Trim Attitude for Orbit Maintenance Burn No. 2 o Burn in Orb Rate o Initiate Powered Flight Navigation		
	+0:55 Commence Orbit Maintenance Burn No. 2 o +X Orbiter Thrust o $\Delta V \approx 4.5$ fps o ≈12 Sec. Burn Time o Orbit = 101 x 101 NM o Terminate Powered Flight Navigation after Burn		
	+0:56 Trim Orb Rate		
147:58	OOS Burn into Circular Orbit for Rendezvous		
148:00	Maneuver to Track Attitude o Pitch Down 15°		
148:02	Initiate Rendezvous Navigation		
148:31	System Status Check		
148:33	Checks Complete		
148:33	IRU Align		
148:38	IRU Align Complete		
148:38	Target TPI Burn o wt = 130° o Continue to Retarget Burn Until Rendezvous Navigation Terminated		

FUNCTIONAL EVENT TIMELINE (Continued)
EASTERLY DESIGN MISSION

Figure 3.2-3

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
148:43	Terminate Rendezvous Navigation		
148:43	Maneuver to TPI Burn Attitude o ≈ +X on Line of Sight to Target o Pitch Up to 27.3°		
148:44	Complete Maneuver		
148:46	Initiate Powered Flight Navigation o System Preburn Checklist		
148:47	Impulsive Time of TPI Burn o +X Orbiter Thrust o ≈ 21 FPS ≈ 13.5 Sec Burn Time o Terminate Powered Flight Navigation after Burn		
148:48	Maneuver to Local Horizontal Attitude o Pitch Down 27.3°		
148:49	Maneuver Complete o Initiate Rendezvous Navigation		
148:54	Target First Midcourse Correction Maneuver		
148:56	Initiate Powered Flight Navigation		
148:57	Impulsive Time of First Midcourse Correction Burn o Nominally Zero ΔV o Burn ΔV in Components o Maintain Local Horizontal Attitude o Terminate Powered Flight Navigation after Burn		
149:04	Target Second Midcourse Correction		
149:06	Initiate Powered Flight Navigation		
149:07	Impulsive Time of Second Midcourse Correction Burn o Nominally Zero ΔV o Burn ΔV in Components o Maintain Local Horizontal Attitude o Terminate Powered Flight Navigation after Burn		

FUNCTIONAL EVENT TIMELINE (Continued)
EASTERLY DESIGN MISSION

Figure 3.2-3

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
149:09	One Crew man to Docking Station		
149:11	Maneuver to Braking Attitude o Orbiter +Z on Line of Sight to Target o Pitch Up 30^{o} o Initiate Powered Flight Navigation o Maintain Inertial Attitude		
149:12	Monitor P/L Line of Sight Rates; Null to Zero		
149:12	Command P/L and OOS Make Ready		
149:14	Verify P/L and OOS Make Ready Successful	149:14	P/L and OOS MAKE READY NO-GO o Possibly Complete Rendezvous, Remove Package from P/L, Space Orbiter and P/L, and Destroy P/L and OOS o Possibly Discontinue Rendezvous and Destroy P/L and OOS
149:17	Terminate Rendezvous Navigation		
149:18	Initiate Braking, Null Approach Velocity to Zero		
149:26	Station Keeping o Visual Inspection of P/L and OOS		
149:30	Extend Docking Rig (Rotate Rig 90^{o})		
149:32	Docking Rig Extended		
149:34	Rigidize Docking Rig		
149:36	Docking Rig Rigidized		
149:40	Approach to Docking Standoff		
149:41	Engage and Latch Docking Ring o Sense Soft Dock o Maneuver to Hard Dock		
149:41	Terminate Powered Flight Navigation		
149:41	Safe P/L and OOS		

FUNCTIONAL EVENT TIMELINE (Continued)
EASTERLY DESIGN MISSION

Figure 3.2–3

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
149:42	Verify P/L and OOS Safe	149:42	P/L and OOS NO-GO Possibly Remove Package from P/L, Separate, Space Orbiter from P/L and/or OOS and Destroy P/L and/or OOS
149:43	Stow P/L and OOS		
149:43	Relax Docking Mechanism and Rotate P/L and OOS 90°		
149:47	Maneuver to "X" Axis on Local Horizontal, BEF o Roll 180°, Pitch ≈ 35° o Establish Orb Rate		
150:00	Perform "On Orbit Functions" Once Each 90 Minutes (See 3:50)		
152:00	Begin Sleep Mode		
161:00	End Sleep Mode		
162:13	Start APU		
162:15	Secure Radiator and Close P/L Bay Door		
162:15	Check Aero Control Surface Operation		
162:16	System Status Checks		
162:17	Radiator Secured		
162:18	Checks Complete		
162:18	IRU Align		
162:23	Target Deorbit Burn		
162:28	Trim Deorbit Burn Attitude		
162:29	Initiate Powered Flight Navigation o System Preburn Checklist		
162:30:06	Commence Deorbit Burn o +X Orbiter Thrust o 250 FPS o 2 Min 40 Sec Burn Time		
162:31:26	Impulsive Deorbit Burn		

FUNCTIONAL EVENT TIMELINE (Continued)
EASTERLY DESIGN MISSION

Figure 3.2–3

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
162:32:46	Deorbit Burn Complete o Terminate Powered Flight Navigation		
162:33	Maneuver to Entry Attitude o Establish Orb Rate		
162:36	Maneuver Complete		
162:36	Commence Entry Preps		
162:36	Begin IRU Align		
162:38	System Status Checks		
162:40	Checks Complete		
162:41	IRU Align Complete		
162:41	Trim Attitude for Entry o Angle of Attack = 30^o		
162:41	Entry Preps Complete		
162:43	Terminate Orbit Navigation o Close Optics Hatches		
162:43	Begin OMS Propellant Dump o Dump through Two Pairs of Opposing YAW Jets		
162:43	Initiate Powered Flight Navigation		
162:44	Entry Interface o Altitude = 400,000 feet		
162:47	Begin VHF Comm Blackout		
162:52	Begin Pullout		
163:00	Terminate OMS Propellant Dump		
163:09	Switch to Aerodynamic Pitch Control		
163:15	End VHF Comm Blackout		
163:15	Lock on Two VOR Stations o Update IRU		

FUNCTIONAL EVENT TIMELINE (Continued)
EASTERLY DESIGN MISSION

Figure 3.2-3

TIME	FUNCTION	TIME	CONTINGENCY FUNCTION
163:20	Lock on Two DME Stations o Continue Automatic Terminal Area Guidance o Velocity < 3000 fps		
163:21	High Key o Begin Automatic Terminal Area Guidance		
163:22	Initiate Transition Maneuver		
163:23	Switch to Aerodynamic Lateral Control o Deactivate ACS Jets		
163:24	End Transition Maneuver o Continue Descent to Intercept Energy Dissipation Circle o Intercept Energy Dissipation Circle at h = 40,000 ft, M = 1.0		
163:27	Turn Toward Low Key Position o Deploy Half Speed Brakes o Airspeed = 275 KTS		
163:27	Final Pre-Landing Checklist		
163:29:40	Low Key o Altitude = 12,000 feet o Turn to Final Approach Heading		
163:30	Begin Final Approach o Computer Generated Glide Slope = 11° o Lock on Localizer o Modulate Speed Brakes and Angle of Attack as Necessary to Maintain Approach Velocity		
163:31:50	Begin Flare for Landing o Intercept ILS Glide Slope at h = 500 feet o Lower Landing Gear		
163:32:15	Touchdown o Speed = 180 KTS o Deploy Drag Chute, Full Speed Brakes o Wheel Brakes		
163:35	Shutdown		

FUNCTIONAL EVENT TIMELINE (Continued)
EASTERLY DESIGN MISSION

Figure 3.2-3

TIME	EVENT	CREW TASK	COMPUTER TASK
–0:58	START PRE-ENTRY PHASE		
–0:58		DETERMINE ENTRY ATTITUDE	COMPUTE ENTRY ATTITUDE MANEUVER START AND STOP TIME, MODES & RATES
	BEGIN MANEUVER TO ENTRY ATTITUDE	MONITOR ATTITUDE MANEUVER OR STICK INPUTS IF MANUAL	GENERATE ACPS MOTOR SIGNALS DISPLAY IRU ANGLES AND ERRORS
	STOP MANEUVER TO ENTRY ATTITUDE	VERIFY FINAL ATTITUDE OR STICK INPUTS IF MANUAL	GENERATE ACPS MOTOR SIGNALS DISPLAY FINAL ATTITUDE AND ERRORS INERTIAL ATTITUDE HOLD
		ALIGN IRU	PERFORM IRU ALIGN
		CHECK NAVIGATION	DISPLAY CURRENT STATE VECTOR, STANDARD DEVIATIONS, ORBIT PARAMETERS
		CHECK SUBSYSTEM STATUS	DISPLAY LRU OR SUBSYSTEM STATUS AND CONFIGURATION
		CHECK ENTRY CONDITIONS	DISPLAY ENTRY PARAMETERS • ENTRY PROFILE • LANDING FOOTPRINT • PREDICTED HEATING & LOAD
		TERMINATE H/S NAVIGATION	STOP ORBITAL FREE FLIGHT NAVIGATION CONTINUE WITH NUMERICAL INTEGRATION
		CLOSE OPTICS HATCHES	GENERATE HATCH CLOSE SIGNALS
		CHECK VEHICLE CONFIGURATION	DISPLAY VEHICLE CONFIGURATION DATA
–0:50	ENTRY ATTITUDE TRIM	MONITOR AUTO TRIM MANEUVER OR STICK INPUTS IF MANUAL	COMPUTE TRIM RESIDUALS GENERATE ACPS MOTOR SIGNALS HOLD INERTIAL ATTITUDE
–0:48	ENTRY INTERFACE		
–0:48	END OF PRE-ENTRY PHASE		

TASK TIMELINE
RETURN TO EARTH – PRE-ENTRY PHASE

Figure 3.2–4

TIME	EVENT	CREW TASK	COMPUTER TASK
–0:48	START ENTRY PHASE		
–0:48	ENTRY INTERFACE	• MONITOR AUTO ENTRY • VERIFY HEAT AND g LOADS CONSTRAINTS ARE NOT VIOLATED • VERIFY VEHICLE IS STEERING TOWARD LANDING SITE • IF MANUAL, INPUT STEERING COMMANDS THROUGH STICK CONTROLLER	• BEGIN POWERED FLIGHT NAVIGATION • PREDICT ENTRY COMMANDS AND CONTROLLING MODES • SENSE MEASURED g LOAD, HEATING AND AIR DATA • MODIFY PREDICTED ENTRY COMMANDS FROM MEASURED DATA • CALCULATE ENTRY STEERING ERRORS AND ATTITUDE ERRORS IN CONTROLLING AXES • GENERATE ACPS MOTOR SIGNALS • COMPUTE DOWN RANGE, CROSS RANGE AND TIME TO GO • AUTO SWITCH OMNI ANTENNAS AS NECESSARY • AUTO SELECT TRANSMIT/RECEIVE FREQUENCIES AS REQUIRED • PROVIDE FOR MANUAL RATE OR ACCELERATION ACPS ROTATIONAL CONTROL MODES • DISPLAY LANDING FOOTPRINT AND h–V DATA TO CREW
–0:45	BEGIN UHF COMMUNICATION BLACKOUT		
–0:44	SENSE 0.05 g BEGIN BLENDED PITCH CONTROL		• COORDINATE ACPS AND ELEVON CONTROL
–0:25	q = 50 PSF BEGIN AERO-PITCH CONTROL		• SWITCH CONTROL SYSTEM TO AERO-PITCH • GENERATE PITCH ACTUATOR SIGNALS
–0:17	END VHF COMMUNICATION BLACKOUT	• CHECK NAVIGATION ERRORS	• COMMUNICATION LOCK-ON VOR STATIONS • UPDATE NAVIGATED STATE USING VOR/DME DATA • DISPLAY NAVIGATION DATA • AUTO SELECT VOR/DME STATIONS AS THEY COME IN RANGE

TASK TIMELINE
RETURN TO EARTH – ENTRY PHASE (Continued)

Figure 3.2–4

TIME	EVENT	CREW TASK	COMPUTER TASK
–0:14.4	BEGIN ENTRY CONTROL PHASE		
–0:14.4	HIGH KEY	• VERIFY HIGH KEY • VERIFY LANDING SITE IS IN CENTER OF FOOTPRINT	• IDENTIFY HIGH KEY & DISPLAY
–0:14.4	BEGIN TRANSITION M = 4	• MONITOR TRANSITION • VERIFY DYNAMIC PRESSURE CONSTRAINTS NOT VIOLATED • PROVIDE STICK CONTROL COMMANDS IF MANUAL	• SWITCH TO TRANSITION CONTROL MODE • COORDINATE ACPS AND LATERAL AERO CONTROL SURFACES • PROVIDE TRANSITION PITCH COMMANDS • PROVIDE FOR MANUAL TAKEOVER
–0:11.4	M = 3		
–0:10	END TRANSITION M = 1.4	• MONITOR AUTO-TERMINAL PHASES • VERIFY ENERGY POTENTIAL REMAINING • VERIFY VEHICLE CONFIGURATION • BEGIN PRE-LANDING PREPARATIONS • VERIFY VEHICLE IS STEERING TO INTERCEPT ENERGY DISSIPATION CIRCLE	• BEGIN USING DME/DME FOR NAVIGATION UPDATE • SWITCH TO LATERAL AERO CONTROL • DEACTIVATE ACPS • MAINTAIN MAXIMUM L/D • MODULATE BANK TO INTERCEPT ENERGY DISSIPATION CIRCLE
–0:08	INTERCEPT ENERGY DISSIPATION CIRCLE	• VERIFY ED CIRCLE • CHECK ENERGY REMAINING • CHECK VEHICLE STATUS • CHECK LIST	• IDENTIFY ED CIRCLE & DISPLAY • COMPUTE ENERGY REMAINING • MODULATE BANK ANGLE TO FLY AROUND ED CIRCLE
–0:05.3	TURN TO LOW KEY		
–0:05.3	END ENERGY CONTROL PHASE		

TASK TIMELINE
RETURN TO EARTH – ENERGY CONTROL PHASE (Continued)

Figure 3.2–4

TIME	EVENT	CREW TASK	COMPUTER TASK
–0:05.3	BEGIN FINAL APPROACH PHASE		
–0:05.3	BEGIN TURN TO LOW KEY	• VERIFY TURN • CONTINUE MONITOR OF AUTO-TERMINAL PHASES • MONITOR ENERGY AVAILABLE & ENERGY REQUIRED • VERIFY SPEED BRAKE EXTENSION • CHECK RADIOS • MONITOR COMPUTER PERFORMANCE VS RAW DATA (AIR, RADIO NAVIGATION, ETC) • COMPLETE ALL CHECKLIST EXCEPT GEAR	• TURN VEHICLE TOWARD LOW KEY • COMPUTE ENERGY LEVEL REQUIRED TO COMPLETE LANDING • MODULATE SPEED BRAKE AND ANGLE OF ATTACK TO ACHIEVE 70% L/D • AUTO SELECT ILS RADIO FREQUENCIES
–0:03.0	HEADING ALIGNMENT CIRCLE INTERCEPT	• VERIFY TURN TO APPROACH HEADING	• TURN VEHICLE TOWARD FINAL APPROACH
–0:02.7	LOW KEY	• VERIFY LOW KEY • MONITOR ENERGY & FLIGHT PATH • CROSS CHECK COMPUTER AND RAW DATA • PROVIDE STICK INPUTS IF MANUAL • VERIFY LOCALIZER LOCK-ON	• GENERATE 11 DEG FLIGHT PATH • IDENTIFY LOW KEY & DISPLAY • CONTROL VEHICLE ALONG GLIDE SLOPE • MODULATE ANGLE OF ATTACK, BANK ANGLE & SPEED BRAKES AS NECESSARY • LOCK ON LOCALIZER • BEGIN RADAR ALTITUDE INPUTS AT 2500 FT
–0:00.8	INTERCEPT ILS GLIDE SLOPE	• VERIFY ILS GLIDE SLOPE INTERCEPT • VERIFY GEAR DOWN • MONITOR ENERGY & FLIGHT PATH • CONTINUE CROSS CHECK • VERIFY FLARE TO 3 DEG GLIDE SLOPE	• IDENTIFY ILS GLIDE SLOPE INTERCEPT • FLARE TO 3 DEG GLIDE SLOPE • SIGNAL TO LOWER LANDING GEAR • BLANK ALL C&W SIGNALS
–0:00.0	TOUCHDOWN	• VERIFY FLARE FOR TOUCHDOWN • VERIFY TOUCHDOWN • MANUAL TAKEOVER FOR ROLLOUT • VERIFY FULL SPEED BRAKES & DRAG CHUTE	• FLARE FOR TOUCHDOWN • IDENTIFY TOUCHDOWN • DEPLOY FULL SPEED BRAKES & DRAG CHUTE • TURN OVER TO MANUAL CONTROL FOR ROLLOUT
	ROLLOUT & STOP	• STEER VEHICLE DOWN RUNWAY • APPLY WHEEL BRAKES	
	END APPROACH & ROLLOUT		

TASK TIMELINE
RETURN TO EARTH – FINAL APPROACH & ROLLOUT PHASES (Continued)

Figure 3.2–4

TIME	EVENT	CREW TASK	COMPUTER TASK
-X:XX	START DEORBIT PHASE		
-2:30	LANDING SITE SELECT	INITIATE LANDING SITE SELECTION	TARGET DEORBIT BURN AS REQUESTED BY CREW • LANDING SITE OPTIONS • TIME OPTIONS • OTHER OPTIONS
		SELECT DEORBIT TIME	COMPUTE DATA PAD (ATTITUDE AND ΔV) FOR SELECTED TIME
		ALIGN IRU	PERFORM IRU ALIGN
		CHECK NAVIGATION	DISPLAY CURRENT STATE VECTOR, ORBIT PARAMETERS, STANDARD DEVIATIONS
		RETRO PRE-THRUST	UPDATE RETRO DATA PAD
		RETRO ATTITUDE	COMPUTE ATTITUDE MANEUVER START AND STOP TIMES, MANEUVER SEQUENCE, MODE AND RATES.
	START ATTITUDE MANEUVER	MONITOR ATTITUDE MANEUVER STICK INPUTS IF MANUAL	GENERATE ACPS MOTOR SIGNALS DISPLAY IRU ANGLES AND ERRORS
	STOP ATTITUDE MANEUVER	VERIFY FINAL ATTITUDE STICK INPUTS IF MANUAL	GENERATE ACPS MOTOR SIGNALS DISPLAY FINAL ATTITUDE & ERRORS HOLD ATTITUDE IN ORBIT RATE
-1:19	START APU	INITIATE APU START	APU START SIGNALS DISPLAY HYDRAULIC PRESSURE, AC POWER, ETC.
		SECURE RADIATOR AND CLOSE CARGO DOOR	
		CHECK AERO-SURFACE OPERATION	
		CHECK SUBSYSTEM STATUS	DISPLAY LRU OR SUBSYSTEM STATUS AND CONFIGURATION
		CHECK VEHICLE CONFIGURATION	DISPLAY VEHICLE CONFIGURATION DATA
		UPDATE RETRO PRETHRUST	UPDATE RETRO DATA PAD
	ATTITUDE TRIM	MONITOR AUTO TRIM MANEUVER OR STICK INPUTS IF MANUAL	COMPUTE TRIM RESIDUALS GENERATE ACPS MOTOR SIGNALS HOLD ATTITUDE IN ORBIT RATE
-1:02	START DEORBIT BURN	VERIFY OMS ENGINE AUTO START OR INITIATE SEMI-AUTO OR MANUAL START SIGNAL	OMS ENGINE START COMMAND BEGIN POWERED FLIGHT NAVIGATION
		MONITOR DEORBIT BURN PROVIDE STICK SIGNALS IF MANUAL GUIDANCE	COMPUTE MEASURED AND "TO GO" ΔV COMPUTE TIME TO GO MAINTAIN ATTITUDE WITH ACPS ROLL SIGNALS AND OMS TVC
-0:59.3	STOP DEORBIT BURN	VERIFY OMS ENGINE AUTO STOP OR INITIATE SEMI-AUTO OR MANUAL STOP SIGNAL	OMS ENGINE STOP STOP COMMAND COMPUTE ΔV RESIDUALS MAINTAIN ATTITUDE HOLD STOP POWERED FLIGHT NAVIGATION AND KEYING ORBIT FREQUENCY FLIGHT NAVIGATION
	TRIM ΔV	MONITOR ACPS AUTO TRIM OR STICK INPUTS IF MANUAL	COMPUTE TRIM RESIDUALS GENERATE ACPS MOTOR SIGNALS HOLD ATTITUDE IN ORBIT RATE
-0:58	END OF DEORBIT PHASE		

TASK TIMELINE
RETURN TO EARTH – DEORBIT PHASE (Continued)

Figure 3.2–4

	ITEMS	ELEMENTS	ASCENT				RENDEZVOUS				ON ORBIT			RETURN TO EARTH						P L HANDLING				FERRY				CREW PARTICIPATION				
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	MGMT	MONITOR	COMD	CONT'L	ANALYSIS
1	ATTITUDE	IMUX, IMUY, IMUZ		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X		X	
2	ATTITUDE RATES	RATE GYRO Φ, Θ, Ψ		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X		X		X	
3	ATTITUDE COMMAND	IMUX, IMUY, IMUZ			X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X		X		X	
4	ATTITUDE ERRORS	IMUX, IMUY, IMUZ		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X		X		X	
5	ΔV (BODY)	BODY ΔVX, ΔVY, ΔVZ		X	X	X																							X		X	
6	ΔV (LV)	LV ΔVX, ΔVY, ΔVZ					X	X	X		X	X	X	X															X		X	
7	ΔV (LOS)	LOS ΔVX, ΔVY, ΔVZ							X	X										X	X	X	X						X		X	
8	ACCELERATION	A_N, A_L, A_T		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X			X	X	X		X		X	
9	THRUST LEVEL	MAIN ENGINES		X	X	X																							X		X	
10		OMS 1, OMS 2					X	X	X	X	X	X	X	X											X	X	X		X		X	
11	ANGULAR DISPLACEMENT	ANGLE OF ATTACK		X	X	X									X	X	X	X							X	X	X		X		X	
12		BANK ANGLE													X	X	X	X														
13		SIDESLIP ANGLE		X	X	X																							X		X	
14	ANGULAR RATES	ATTACK RATE													X	X	X	X							X	X	X	X	X		X	
15	AUTOPILOT MODES	AUTO RATE	X	X	X	X																							X			
16		ATTITUDE HOLD	X				X	X	X	X	X	X	X	X	X					X	X	X	X						X			
17		BANK CONTROL	X													X	X	X						X			X		X			
18		ATTACK CONTROL	X													X	X	X						X			X		X			
19		ATTITUDE HOLD	X															X						X		X	X	X	X			
20		VOR, G'S, LOC HOLD	X															X						X		X	X	X	X			
21		HEADING HOLD	X															X						X		X	X	X	X			
22		AREA NAVIGATION	X																					X		X		X	X			
23		AUTOLAND	X															X						X			X	X	X			
24	ATTITUDE MANUAL MODE	RATE CONDITION 'ATTITUDE HOLD	X				X	X	X	X	X	X	X	X	X	X					X	X	X					X			X	
25		ACCELERATION	X				X	X	X	X	X	X	X	X	X						X	X	X					X			X	
26		PULSE	X				X	X	X	X	X	X	X	X	X						X	X	X					X			X	
27		BANK CONDITION	X															X						X	X	X	X	X			X	
28		FLIGHT PATH ANGLE CONDITION	X															X						X	X	X	X	X			X	
29		NOSE WHEEL STEER	X																X					X	X		X				X	
30		RATE CONDITION	X		X	X												X						X	X	X	X	X			X	
31	ATTITUDE RATES	HIGH-LOW	X				X	X	X	X	X	X	X	X	X					X	X	X	X					X	X		X	
32	AERO SURFACE POSITION	INDICATOR	X														X	X	X					X	X	X	X		X		X	
33	CONTROL ENABLE	CONTROL STICK	X											X			X	X	X					X	X	X	X				X	
34		RUDDER PEDALS	X											X			X	X	X					X	X	X	X				X	
35		SPEED BRAKE	X											X			X	X	X					X	X	X	X				X	
36		FLAPS	X											X			X	X	X							X	X				X	
37		ABES THROTTLES																X	X					X	X	X	X				X	
38		ATTITUDE CONTROLLER	X		X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X								X	
39		MANEUVER CONTROLLER	X		X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X								X	
40		ATTITUDE CONTROLLER SELECT	X		X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X						X		X	
41		MANEUVER CONTROLLER SELECT	X		X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X						X			
42		ATTITUDE CONTROLLER SYSTEM	X		X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X						X			
43		MANEUVER CONTROLLER SYSTEM	X		X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X						X			
44		FDI REFERENCE	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X			
45		FDI SELECT	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X			

MISSION SEQUENCE	ASCENT	RENDEZVOUS	ON ORBIT	RETURN TO EARTH		P L HANDLING	FERRY
MISSION PHASES	1. PRELAUNCH	5. CATCH UP	9. HOHMAN TRANSFER	12. DEORBIT	15. ENERGY CONT	18. DOCKING	22. PREFLIGHT
	2. MATED FLIGHT	6. RELATIVE	10. OUT OF PLANE	13. PREENTRY	16. FINAL APPROACH	19. UNDOCKING	23. TAKEOFF
	3. SEPARATION	7. TERMINAL	11. CORR COMB	14. ENTRY	17. ROLLOUT	20. STATION KEEP	24. CRUISE
	4. ORBIT INSERTION	8. STATION KEEP				21. P L DEPLOY RETRIEVE	25. DESCENT AND LAND

PARAMETER REQUIREMENTS – CONTROL PARAMETERS

Figure 3.2–5

	ITEMS	ELEMENTS	ASCENT				RENDEZVOUS				ON ORBIT			RETURN TO EARTH						P/L HANDLING				FERRY				CREW PARTICIPATION				
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	MGMT	MONITOR	COMD	CONT'L	ANALYSIS
1	IMU ACCELERATION	IMU AX, AY, AZ	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X		X	X	X		X		X	X
2	IMU ATTITUDE	IMUX, IMUY, IMUZ	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X
3	IMU ALIGNMENT	PRELAUNCH	X																		X			X					X	X	X	
4		COURSE ALIGNMENT					X	X	X	X	X	X	X	X	X							X							X	X		
5	HORIZONTAL SENSOR	INSTRUMENT LOCAL VERFICAL					X	X	X	X	X	X	X	X	X					X	X	X	X						X			X
6	S-BAND RANGING	RANGE TO TARGET						X	X																				X		X	X
7	STAR TRACKER	STAR ELEVATION & DECLINE					X	X	X	X	X	X	X	X	X							X							X	X		X
8	DME	DISTANCE TO STATION															X	X								X	X		X		X	X
9	VOR	BEARING TO STATION															X									X			X		X	X
10	PRECISION DME	DISTANCE TO TOUCHDOWN																	X								X		X		X	X
11	BARO ALTIMETER	ALTITUDE															X	X	X					X	X	X	X		X		X	X
12	SPEED & VERTICAL SPEED	IAS & MACH NO & RATE OF CLIMB OR DESCENT		X													X	X	X										X		X	X
13	TEMPERATURE SENSORS	BODY TEMPERATURES														X													X		X	X
14		TOTAL TEMPERATURE															X	X	X						X	X	X		X		X	X
15	RADAR ALTIMETER	PRECISION ALTITUDE																	X								X		X		X	X
16	TRAJECTORY	ALTITUDE		X	X	X										X	X	X							X	X	X	X	X			X
17		VELOCITY		X	X	X										X	X	X	X						X	X	X	X	X			X
18		HEADING		X	X	X										X	X	X	X						X	X	X	X	X			X
19		LATITUDE & LONGITUDE		X	X	X										X	X	X								X		X	X			X
20		FLIGHT PATH AMPLE		X												X	X	X							X	X		X	X			X
21		ORBITAL PARAMETERS					X	X	X	X	X	X	X	X	X					X	X	X	X					X	X			X
22	TARGETING	VELOCITY MAGNITUDE	X		X	X					X	X	X															X	X		X	X
23		RADIAL VELOCITY	X		X	X					X		X															X	X		X	X
24		OUT OF PLANE VELOCITY	X		X	X						X	X															X	X		X	X
25		RANGE	X		X	X																						X	X		X	X
26		POSITION COORDINATES	X		X	X					X	X	X											X	X	X	X	X	X		X	X
27		TARGET EPHEMERIES	X				X	X	X							X	X	X		X	X	X						X	X		X	X
28		RENDEZVOUS TECHNIQUE	X																									X	X		X	X
29		TIME (RENDEZVOUS OR LANDING)	X				X	X	X					X										X		X		X	X		X	X
30		LANDING SITE LOCATION												X										X		X		X	X		X	X
31		HIGH KEY LOCATION														X												X	X		X	X
32		LOW KEY LOCATION															X	X									X	X	X		X	X
33	COMPOSITE DATA	ALTITUDE-VELOCITY		X	X	X										X												X	X		X	X
34	&	GROUND TRACKS		X	X	X								X												X		X	X		X	X
35	PREDICTIONS	TARGET RELATIVE					X	X	X	X										X	X	X						X	X		X	X
36		LANDING SITE RELATIVE															X	X					X					X	X		X	X
37		LANDING FOOTPRINT												X	X	X												X	X		X	X
38		ENERGY-RANGE															X	X									X	X	X		X	X
39		ALTITUDE-RANGE																X									X	X	X		X	X
40		AZIMUTH-RANGE																X									X	X	X		X	X
41	TIME TO GO	LIFTOFF	X																									X	X	X	X	X
42		SEPARATION		X																								X	X	X		X
43		MAIN ENGINES START STOP		X	X	X																						X	X	X		X
44		OMS ENGINES START STOP					X	X	X		X	X	X	X														X	X	X		X
45		ACPS TRANSLATION START STOP								X			X							X	X	X	X					X	X	X		X
46		ATTITUDE START STOP					X	X	X	X	X	X	X	X	X							X						X	X	X		X
47		TOUCHDOWN												X	X	X	X	X							X	X	X	X	X	X		X
48	DERIVED DATA	ALTITUDE RATE		X	X	X										X	X	X							X	X	X		X		X	X
49		ANGLE OF ATTACK		X	X	X										X	X	X							X	X	X		X		X	X
50		ANGLE OF ATTACK RATE														X	X	X								X	X		X		X	X
51		ANGLE OF BANK														X	X	X							X	X	X		X		X	X
52		TOTAL HEATING														X													X		X	X
53		RELATING RANGE RATE						X	X	X													X						X		X	X
54		RELATIVE ATTITUDE								X										X	X		X						X		X	X
55		LOS RATES						X	X																				X		X	X
56		ΔV REQUIRED		X	X	X	X	X	X		X	X	X	X																		
57		ΔV TO GO		X	X	X	X	X	X		X	X	X	X															X		X	X
58		DOWN RANGE TO GO												X	X	X	X												X		X	X
59		CROSS RANGE TO GO												X	X	X	X												X		X	X
60		PERCENT L/D															X	X							X	X	X		X		X	X
61		TOTAL ENERGY															X	X									X		X		X	X
62		TRUE AIRSPEED															X	X							X	X	X		X		X	X
63		GROUND SPEED															X	X								X	X		X		X	X
64		DYNAMIC PRESSURE														X	X	X							X	X	X		X		X	X

MISSION SEQUENCE	ASCENT	RENDEZVOUS	ON ORBIT	RETURN TO EARTH		P/L HANDLING	FERRY
	1. PRELAUNCH	5. CATCH UP	9. HOHMAN TRANSFER	12. DEORBIT	15. ENERGY CONT	18. DOCKING	22. PREFLIGHT
MISSION	2. MATED FLIGHT	6. RELATIVE	10. OUT OF PLANE	13. PREENTRY	16. FINAL APPROACH	19. UNDOCKING	23. TAKEOFF
PHASES	3. SEPARATION	7. TERMINAL	11. CORR COMB	14. ENTRY	17. ROLLOUT	20. STATION KEEP	24. CRUISE
	4. ORBIT INSERTION	8. STATION KEEP				21. P/L DEPLOY/RETRIEVE	25. DESCENT AND LAND

PARAMETER REQUIREMENTS – NAVIGATION & GUIDANCE PARAMETERS (Continued)

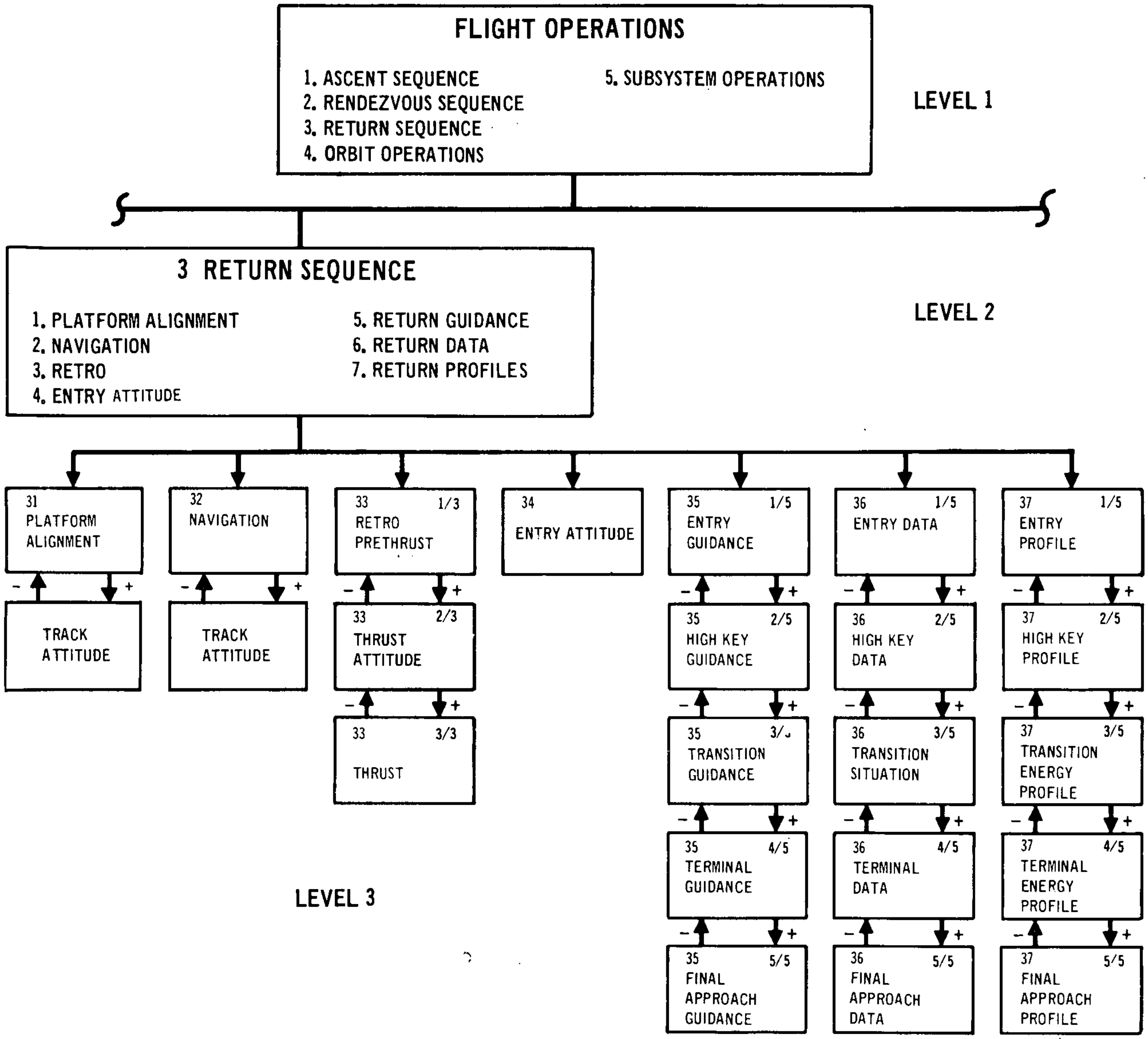
Figure 3.2–5

3.3 Display Concept and Calling Procedures - During the course of the mission the crew members are called upon to perform various tasks. These tasks may involve the use of computer software for successful completion. A rapid, reliable, and easily followed set of procedures must be provided by which the crew can capture the attention of the software needed to perform the desired task. Having obtained software attention, a channel of communication between the man and the machine must be established through which the man may control the computational data and logical progression of the software.

The display and control philosophy contained herein, which is to be investigated in the simulation studies to follow, was formulated in an attempt to satisfy the above man machine interface requirements.

In addition to the conventional flight instruments, each crew member is provided a Cathode Ray Tube (CRT) display and keyboard to interface with the flight computer. The keyboard and CRT are mounted in the same field of view. A third CRT and keyboard combination is mounted on the center pedestal. The CRT's are used to display supplementary information to the cenventional flight instruments during critical phases of the mission, thereby enabling the crew to more easily interpret their flight status.

Using the results of the time line analysis, the CRT display calling procedures have been structured. A simple logical progression to a desired display and corresponding crew/computer interface utilizing that display can be accomplished with a minimal keyboard activity. The displays are accessible to any of the three CRT's by exercising the calling procedures on the keyboard associated with the CRT. The complete display structure for the Space Shuttle Return Sequence is illustrated in Figure 3.3-1. This figure is used in the following definition of the calling procedures.



RETURN SEQUENCE DISPLAY STRUCTURE

Figure 3.3–1

The displays are grouped on three levels, each level corresponding to a step to be taken in the calling procedures. The first level, an index to the major flight operations, is called to start the calling procedure by keying in "OPS" from the keyboard. The second level display is called by selecting the desired category from the level 1 display and keying the category number. This level presents an index to the basic tasks to be performed with aid of the level 3 displays. These displays are the operational displays providing the man-machine interface. As in progressing from level 1 to level 2, a level 3 display is called by selecting a category from the level 2 display and keying the category number. It will be observed from the figure that the level 3 display numbers (found in the upper left hand corner of the display) are derived from the category selections from levels 1 and 2.

The level 3 displays can be further divided into a number of pages, each identifying a highly related task associated with the accomplishment of the basic task. As indicated in Figure 3.3-1, stepping from page to page may be accomplished by keying "+" (forward step) or "-" (reverse step) on the keyboard. The present page number is identified along with the total number of pages in the upper right corner of the display.

Software programs required for the performance of a given task are coordinated with the calling of a display. When the display is procured, the servicing software is available for computational and control purposes. It goes without saying that the software routines used for servicing the calling procedures are continually active. The crew may use the information provided by the display to instruct the software as to the desired action to be taken in the performance of the given task.

The instructions may consist of the insertion of data to be used in computation, insertion of logical parameters and/or execute commands, depending upon which functions are allowed by the display format.

Data insertion is allowed by identifying the parameter for which data may be inserted by a number enclosed in a square; the number is referred to as an ITEM number. A depression of the ITEM key on the keyboard alerts the software that data insertion is impending. The crew inserts the item number and data. When the item number is identified, the data displayed for the associated parameter will be blanked on the screen. As new data is keyed in, this data will be displayed in a right to left shifting sequence. Data may be entered using the same procedure for any item number appearing on the screen. If a mistake in entry is made, a clear function is provided by depressing the ITEM key and inserting the same item number as was being used when the incorrect entry was made. Inserted data does not get stored in computer memory until an ENTER function is commanded from the keyboard. No disciplinary action is taken when an improper entry, detectable by software, is made other than that taken on the entry of an illegal item number (that is an item number entered which does not agree with any on the screen). In all cases except the latter the input is ignored. In the latter case, the data insertion software will accept no further inputs until the ITEM key is again depressed and an allowable item number as shown on the screen is entered.

The command to execute a given program or control function is given by depressing the EXECUTE key on the keyboard. The software logic determines what program or command is to be executed on the basis of the display present on the CRT associated with the keyboard from which the command is given. If the function does not apply to this display, the command is ignored.

A supplementary display and control management function is provided by a data dispatch system. By manipulation of the switches on the data dispatch panel in the crew station, a display appearing on any CRT may be dispatched to either or both of the remaining two, thereby eliminating the necessity of repeating the calling procedures to obtain the same display at more than one CRT terminal. Provision is also made for interchanging the pilot and copilot's displays by depressing a single switch on the panel.

4. SIMULATION

4.1 Simulation Objectives - The objectives of a real-time flight simulation are as follows:

- Evaluate a design concept for the Shuttle flight crew in which displays and controls for a conventional airplane are mixed with the displays and controls of a spacecraft.
- Ascertain the maturity of the design requirements for the flight crew/computer interface as follows:
  - size and number of display & keyboard units
  - procedures for calling data displays
  - procedures for inserting data
  - display formats & data
  - requirements for graphics type displays
- Determine the feasibility of the overall command and control capability for the guidance, navigation and control functions in a simulated flight covering both orbital and atmospheric operations.

To best meet the objectives, critical phases of the Return Sequence will be investigated individually and the necessary improvements made before the complete Return Sequence is evaluated.

4.2 List of Variables

α	angle of attack (DEG)
α_C	guidance angle of attack command (DEG)
α_{DAMP}	phugoid damping command (DEG)
α_{MAX}	maximum allowable angle of attack (DEG)
α_{MIN}	minimum allowable angle of attack (DEG)

4.2 List of Variables (Continued)

α_{NOM}	nominal angle of attack (DEG)
A_X, A_Y, A_Z	body X, Y and Z components of load factor (g's)
β	angle of sideslip (DEG)
b	lateral aerodynamic reference length (feet)
B	bank angle (DEG)
B_C	guidance bank command (DEG)
$C_{l\beta}$	roll aero derivative with respect to sideslip
$C_{n\beta}$	yaw aero derivative with respect to sideslip
CONST	constraint flag ($\neq$ 0 if on temperature or 2g constraint)
δa	equivalent aileron deflection (DEG)
δac	aileron command (DEG)
δe	equivalent elevator deflection (DEG)
δec	elevator command (DEG)
δr	rudder deflection (DEG)
δrc	rudder command (DEG)
δSB	speed brake deflection (DEG)
δSBc	speed brake command (DEG)
$\Delta\psi$	heading error (DEG)
$\Delta\psi_{AC}$	change in heading required to direct the vehicle toward the heading alignment circle (DEG)
DEV	localizer horizontal deviation angle (DEG)
DLODV	change in vertical L/D required for trajectory control
D_T	distance between the vehicle and the heading alignment circle (feet)
E	normalized energy (feet^2/second^2)
γ	flight path angle (DEG)
γ_{HOLD}	flight path angle command (DEG)
g	local gravity (feet/second^2)

4.2 List of Variables (Continued)

H	altitude above Fisher ellipsoid (feet)
h_{error},HERR	vertical error between vehicle and desired glideslope (feet)
HMIN	minimum allowable altitude at α (feet)
HMINC	minimum allowable altitude at α_c (feet)
IMP	accumulated RCS impulse (pound-second)
INFORMB	data array used for drawing fixed format displays
I_X	body X axis moment of inertia (slug-feet^2)
I_Z	body Z axis moment of inertia (slug-feet^2)
KTUBE	index specifying the CRT display data to be updated
L_A, M_A, N_A	body X, Y and Z components of aero torque (foot-pounds)
LODC	commanded L/D
LODLC	commanded lateral L/D
LODVC	commanded vertical L/D
LODLR	required lateral L/D
LODVR	required vertical L/D
LSTART	index used to start reading INFORMB display format array
L_T, M_T, N_T	body X, Y and Z components of thruster torque (foot-pounds)
M	Mach number
MODE	entry guidance mode 1 : $(\frac{L}{D})c \geq (\frac{L}{D})_{MAX}$ 2 : $(\frac{L}{D})_{MIN} < (\frac{L}{D})_C < (\frac{L}{D})_{MAX}$ 3 : $(\frac{L}{D})_C < (\frac{L}{D})_{MIN}$
ϕ	earth referenced latitude (DEG)
ϕ_G, θ_G, ψ_G	platform gimbal angles (pitch-yaw-roll sequence) relating body axes to platform axes (DEG)

4.2 List of Variables (Continued)

ϕ_N, θ_N, ψ_N	Euler angles (yaw-pitch-roll sequence) relating body axes to N-E-D axes (DEG)
ϕ_P, θ_P, ψ_P	Euler angles relating platform axes to earth centered inertial axes (DEG)
ψ	vehicle heading (DEG)
ψ_C	heading of vector from center of energy dissipation circle to vehicle (DEG)
ψ_{ED}	desired vehicle heading during energy dissipation phase (DEG)
p, q, r	body x, y and z components of rotational rate
p_c, q_c, r_c	roll, pitch and yaw rate command (degrees/second)
PHASE	terminal area guidance phase 1 : energy dissipation (ED) 2 : acquisition (AC) 3 : heading alignment (HA) 4 : final approach (FA)
$\bar{q}$	dynamic pressure (pounds/feet^2)
R	radius vector to vehicle from earth center (feet)
r'	estimated turn radius based on instantaneous velocity and 40 degrees bank (feet)
RAC	range to be flown during acquisition
RCMAX	maximum crossrange capability (NM)
RCT	crossrange to entry target (NM)
RCTHK	crossrange to high key target (NM)
RCTHKE	predicted crossrange travel to high key based on current α and B (NM)
RDMAX	maximum downrange capability (NM)
RDMIN	minimum downrange capability (NM)
RDT	downrange to entry target (NM)
RDTHK	downrange to high key target (NM)

4.2 List of Variables (Continued)

RDTHKE	predicted downrange travel to high key based on current α and B (NM)
REST	estimated ground track range during terminal area (feet)
R_{FA}	range to be flown during final approach (feet)
R_{HA}	range to be flown during heading alignment (feet)
R_M	maximum range capability during terminal area (feet)
R_N	nominal range capability during terminal area (feet)
r_T	nominal desired turn radius (feet)
s	reference aerodynamic surface area ($feet^2$)
θ	earth referenced longitude (DEG)
T	environmental time (seconds)
TEMP	underside skin temperature ($^\circ$F)
V	instantaneous relative velocity (feet/second)
V_N, V_E, V_D	North, East and Down components of relative velocity (feet/second)
ω_D	Dutch roll natural frequency (radian/second)
W_N, W_E, W_D	North, East and Down components of wind velocity (feet/second)
X	horizontal distance to vehicle along steep glideslope (feet)
Y	lateral deviation distance from glideslope (feet)
$\dot{Z}$	sink rate (feet/second)
$\dot{Z}_{NOM}$	nominal sink rate (feet/second)

4.3 Simulator Mechanization - The High Fidelity Shuttle Simulator (HFSS) is a fully instrumented, two-man crew station capable of simulating all orbit and atmospheric flight phases of any shuttle mission. Features of the simulator include:

(1) A fixed base crew station equipped with flight controls, instruments, displays and switching panels.

(2) A dual, virtual image, out-the-window display system.

(3) A sound system which provides important aural cues to the pilots.

(4) Three cathode ray tubes (CRT's), keyboards and controls to provide raster and stroke-written cockpit displays.

(5) Subsystem simulation software.

(6) Environmental simulation software.

The functional block diagram shown in Figure 4.3-1 illustrates the communication between the HFSS, the CDC 6600 computer and the Varian 620 i (IDIIOM) graphics computer. The following paragraphs discuss in more detail the cockpit and vehicle simulations.

4.3.1 Cockpit Simulation - The cockpit simulation consists of the following:

(1) Visual and audio effects

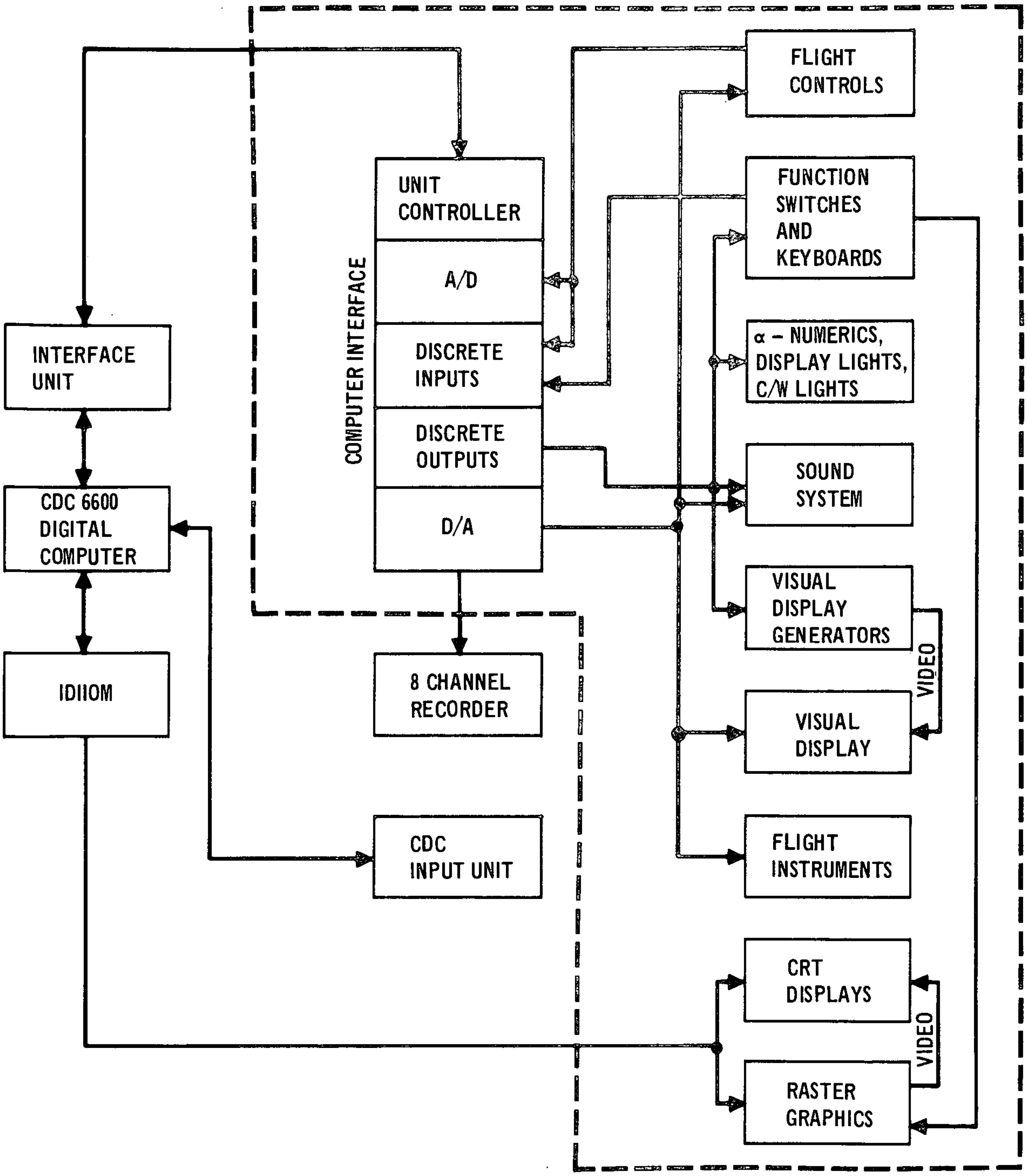
(2) Flight instruments

(3) Flight controls

(4) Subsystem controls

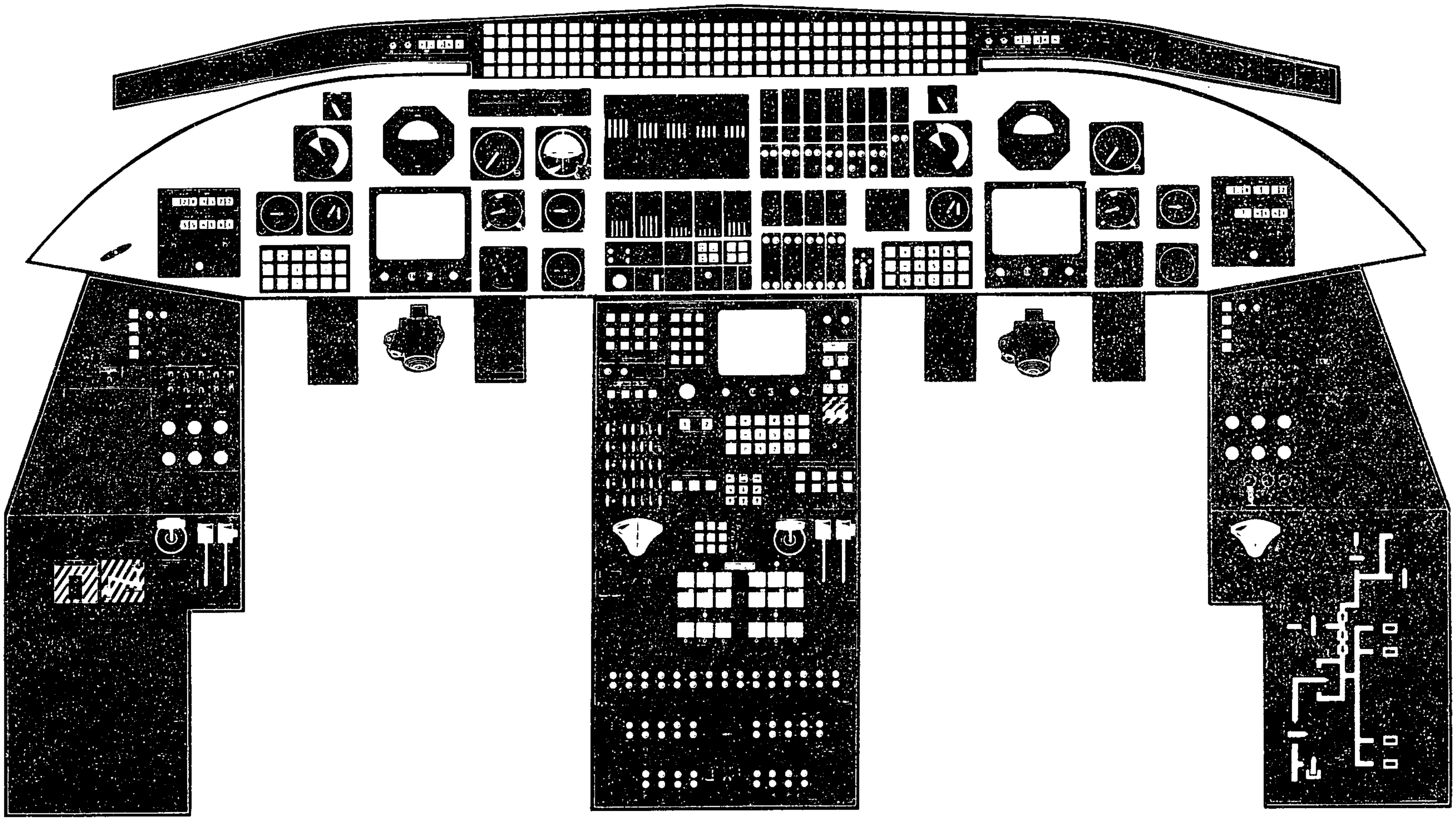
(5) CRT displays and controls

The cockpit displays and controls arrangement is illustrated in Figure 4.3-2.



HFSS FUNCTIONAL BLOCK DIAGRAM
High Fidelity Shuttle Simulator

Figure 4.3–1



SPACE SHUTTLE ORBITER INSTRUMENT PANEL

Figure 4.3–2

4.3.1.1 Visual and Audio Effects - The HFSS out-the-window display system provides a virtual image displays simultaneously in the forward windows of the pilot and the co-pilot. Each display consists of spherical mirror segments, beam splitters,and television monitors optically arranged as shown in Figure 4.3-3. The landing displays provided by a horizon generator and a terrain map and the in-orbit displays provided by a star-earth generator are presented on a 525 line color TV monitor. The pilot's field of view is approximately 44 degrees vertically and 52 degrees horizontally.

The HFSS sound simulation unit provides audio cues of aerodynamic, engine, runway and thruster noises. Four speakers are located in the cockpit to provide a stereo effect.

4.3.1.2 Flight Instruments - The active flight displays on the HFSS are the following:

(1) ADI's (2) - three axis Apollo LM attitude ball is mechanized with six Flight Director Indicators (FDI's), three for attitude commands and three for attitude rates.

(2) Mach/airspeed indicator (2) - indicated air speed and Mach number is presented.

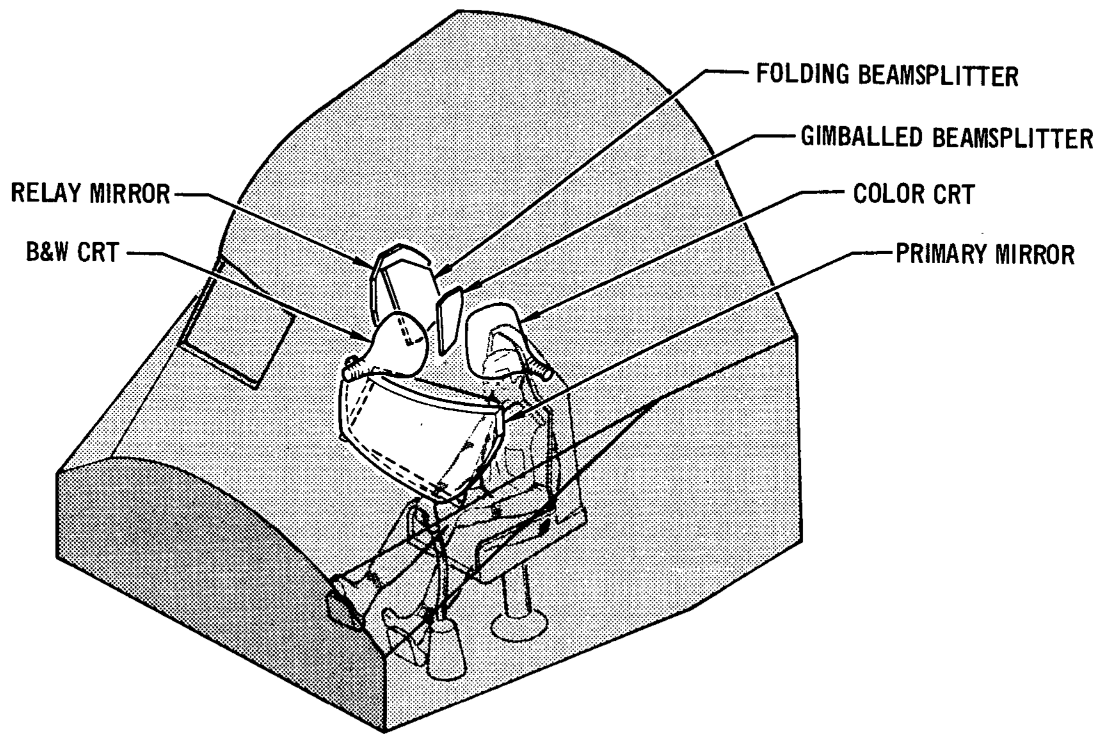
(3) Angle of attack indicator (2) - angle of attack is presented.

(4) Load factor indicator (pilot only) - vertical load factor in g's is presented.

(5) Barometric altimeter (2) - barometric altitude is presented.

(6) Radar altimeter (2) - terrain altitude is presented.

(7) HSI's (2) - vehicle heading relative to north, selected course, heading marker, glideslope and localizer deviations and a TO-FROM indicator are presented.



VISUAL DISPLAY SYSTEM – FUNCTIONAL DIAGRAM

Figure 4.3–3

(8) Surface deflection indicators (copilot only) - elevator, aileron, and rudder deflections are presented.

(9) DME 1 and DME 2 (2) - digital readout of DME range to two selected stations are presented.

(10) GET/GMT (2) - digital readout of Ground Ellapsed Time and Greenwich Mean Time are presented.

(11) Event timers (2) - digital readout of event countdown is presented.

4.3.1.3 Flight Controls - The active flight controls on the HFSS are the following:

(1) Attitude controllers (2) - Apollo attitude controllers provide for 3 axis control in orbit and 2 axis control in atmospheric flight.

(2) Rudder pedals - rudder pedals provide yaw control in atmospheric flight and nose wheel steering.

(3) Speed brake controller - the speed brake controller provides proportional control of the speed brake surfaces.

(4) Landing gear handle - the landing gear handle initiates deployment of the landing gear.

(5) Drag chute handle - the drag chute handle initates deployment of the landing drag chute.

(6) Nose wheel steering switch - this switch provides for steering while on the runway.

(7) Translation controllers (2) - the controllers activate translation thrust.

4.3.1.4 Subsystem Controls - The active subsystem controls on the HFSS are the following:

(1) FDI reference select (2) - this switch selects IRU, horizon scan, trackers, or computer as the reference for the attitude FDI's.

(2) Guidance mode selector - this selector activates the appropriate guidance computer mode (e.g. Ascent, Rendezvous and Return)

(3) Autopilot panel - this panel provides for configuration of the atmospheric control system.

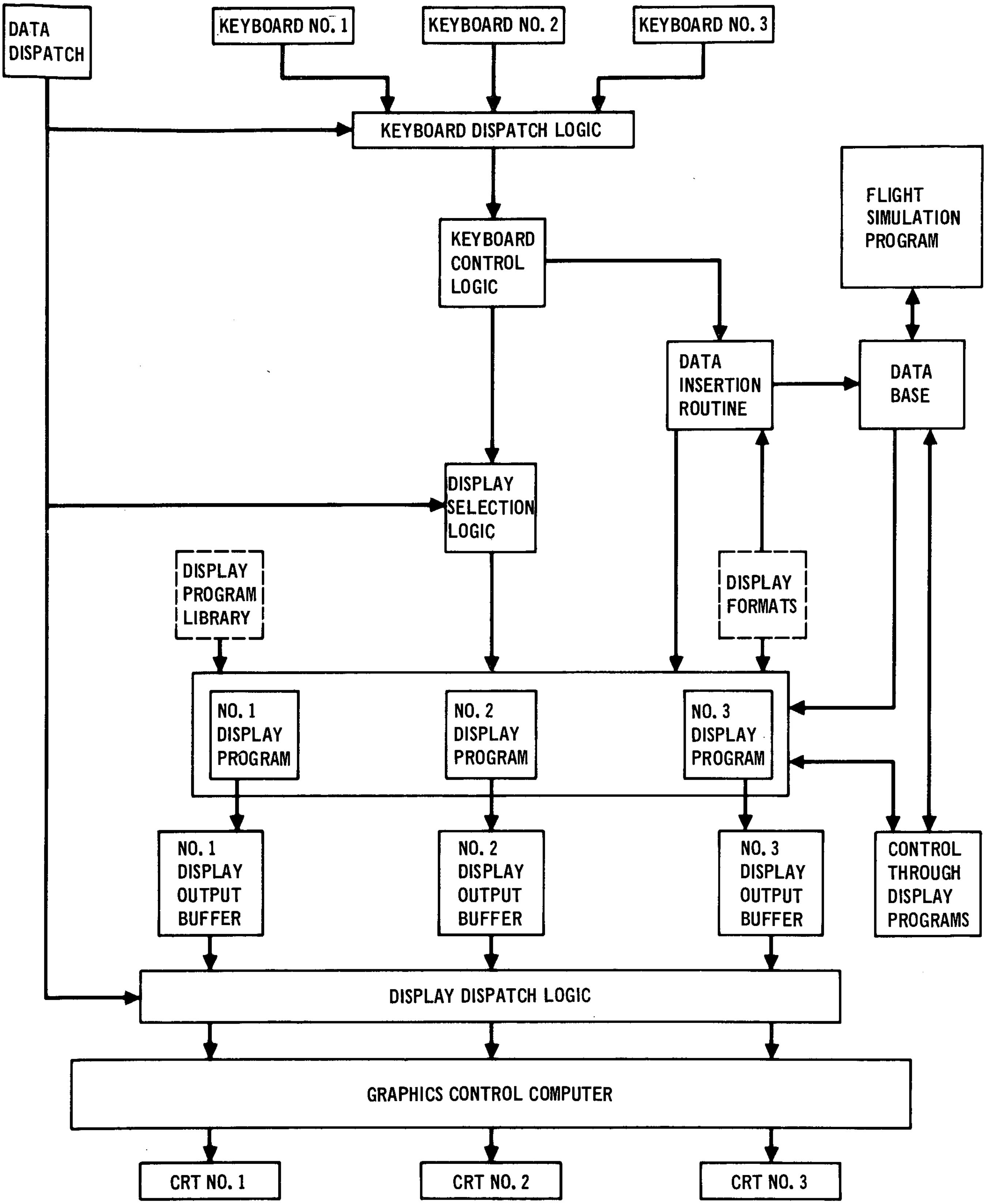
(4) RCS mode control panel - this panel provides for configuration of the on-orbit control system.

(5) VOR/DME A and B selectors - two VOR/DME channels or corresponding frequencies can be selected.

(6) ILS selector - an ILS channel or frequency can be selected.

(7) IRU panel - this panel is used for selecting the IRU and for alignment of the IRU.

4.3.1.5 CRT Displays and Controls - There are three display and keyboard terminals in the HFSS for simulating the crew interface to the flight computer. The displays are mechanized with three cathode ray tubes (CRTS). The three keyboards are mechanized with eighteen keys apiece. A data dispatch keyboard with nine keys is used for interchanging the displays and keyboard functions from one terminal to another and for simulating ground uplink-downlink communications. A diagram of the software which was developed to mechanize the display keyboards for the Phase I Crew Interface Study is shown in Figure 4.3-4.



D & C SOFTWARE DIAGRAM

Figure 4.3–4

The keyboard control logic accepts data from the three keyboards, indicating what key on which keyboard has been depressed. The input data is interpreted by the keyboard logic and converted into instructions or meaningful data which is used by other routines necessary to perform the desired function commanded by the depressed key. All data generated by the keyboard control logic is identified and stored according to keyboard number.

The response to the commands is observed on a CRT associated with the requesting keyboard. The function of the display select logic is to interrogate the keyboard control logic data stored for the three keyboards and determine which display is required on each of the three CRT's. The CRT numbering agrees with keyboard numbering, each CRT having its own control keyboard. Once the display number is determined, the corresponding display program is selected from the display program library and used to generate the required instructions needed by the graphics terminal to draw the desired display. The data generated by the display program is stored in a buffer area assigned to each CRT from which transfer to the graphics terminal is made.

The display program receives data from one or more of the three basic sources, the display format block, the data base block, and from the data insertion routine when in use. The format data block contains data necessary to inform the display program of what data is required to be displayed and at what position on the screen the data is to be displayed. Also included is the address at which specific data may be found in the data base. The data format block may also contain special vector drawing routines, those routines which are used frequently in one or more displays. The data base receives data from the flight simulation programs and from a data insertion routine.

The data insertion routine is used to modify data in computer memory. When this routine is in use, the keyboard entries are used to formulate a data word and an address where the data is to be stored. The routine will not recognize a request for inserting data into any storage area which is not associated with the current display. The data word is stored in display code for display purposes and binary for insertion purposes. The data is held in temporary storage until an ENTER command is received via keyboard input. When indicated, the display of "to be changed" data is made from the temporary storage area.

The data dispatch logic (keyboard and display), allows the crew to combine or interchange the CRT displays and keyboard functions with one another depending on what switch has been depressed on the panel. For example, if the panel switch that transfers the display on the pilot's CRT to the copilot's CRT is depressed, the following occurs:

(1) The display for the copilot's CRT is generated from the same buffered data as the pilot's CRT.

(2) Inputs from the copilot's keyboard will be treated as though they were input from the pilot's keyboard.

(3) The CRT's and keyboards on the pilot's side and the copilot's side operate as one.

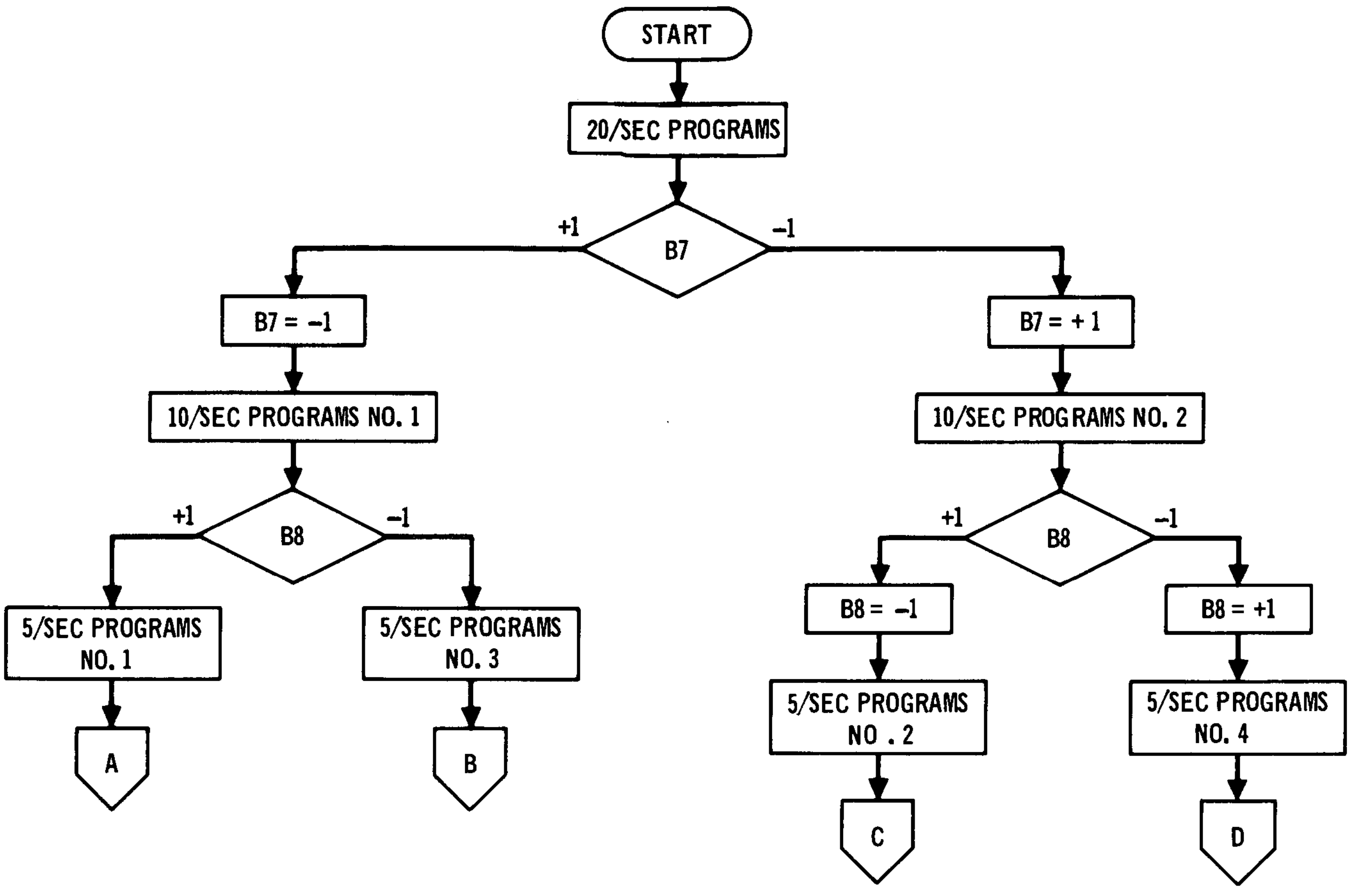
The control through display programs are interfaced with the flight simulation programs through the data base. The software logic is designed so that keyboard input commands to execute a control through display program will not be acknowledged unless the corresponding display program is currently being executed.

The control commands or data management functions cannot be exercised unless the display affected by the inputs is currently active on one of the CRT's. This philosophy is that of "you cannot control a function that is not displayed."

The simulation software as developed for the Space Shuttle simulation is comprised of a number of functional subroutines (such as equations of motion routines, re-entry guidance routines and terminal guidance routines) which are called into execution by an executor routine on a time schedule basis. The executor routine is entered at 50 millisecond time intervals and has in addition to other simulation control functions a number of calling blocks into which calls to the various subroutines are inserted. The section containing the calling blocks is diagrammed in Figure 4.3-5. From the figure it is apparent that in addition to the 20/SEC calling block, two 10/SEC, four 5/SEC and twenty 1/SEC calling blocks are provided by the executor logic. This arrangement allows a computational work load distribution over twenty 50 millisecond passes eliminating the necessity of having to do all computations on a single pass. Engineering judgement, as to the computational rate required for each routine and in what order routines should be called, dictates in what calling block the call to the routine should be placed.

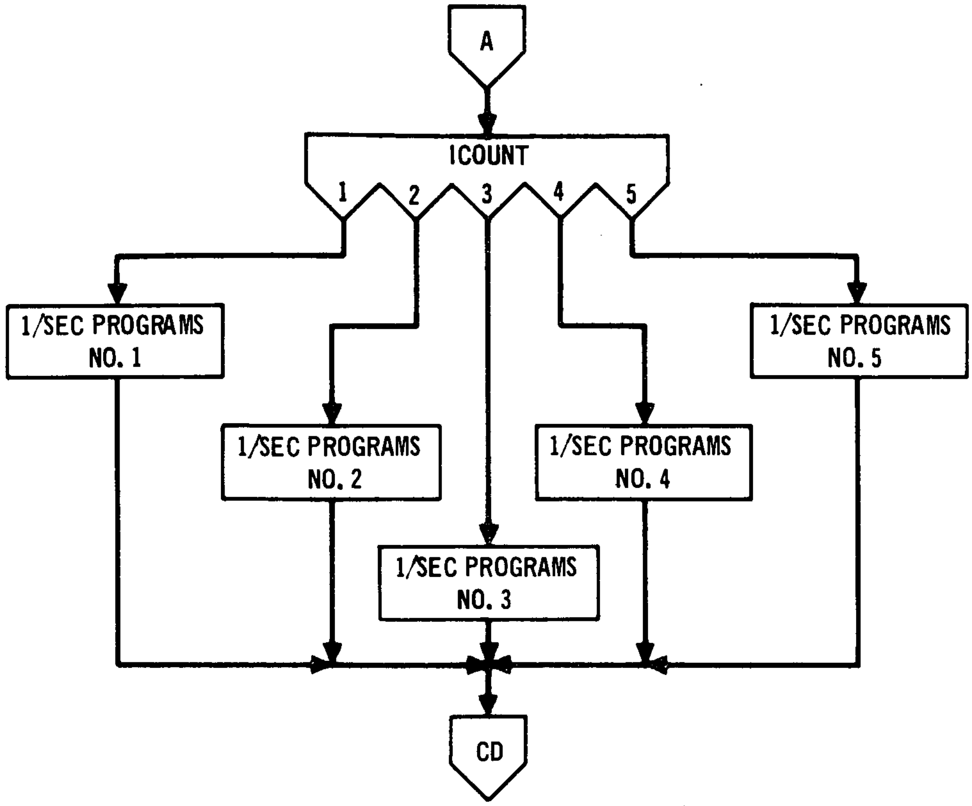
The display and control software package being developed in this study are being incorporated into the High Fidelity Space Shuttle Simulator presently under development. The display and control functions will be called at the 20/SEC rate. The various subroutines making up the software package are called in the order shown in Figure 4.3-6. They are discussed individually in the following paragraphs.

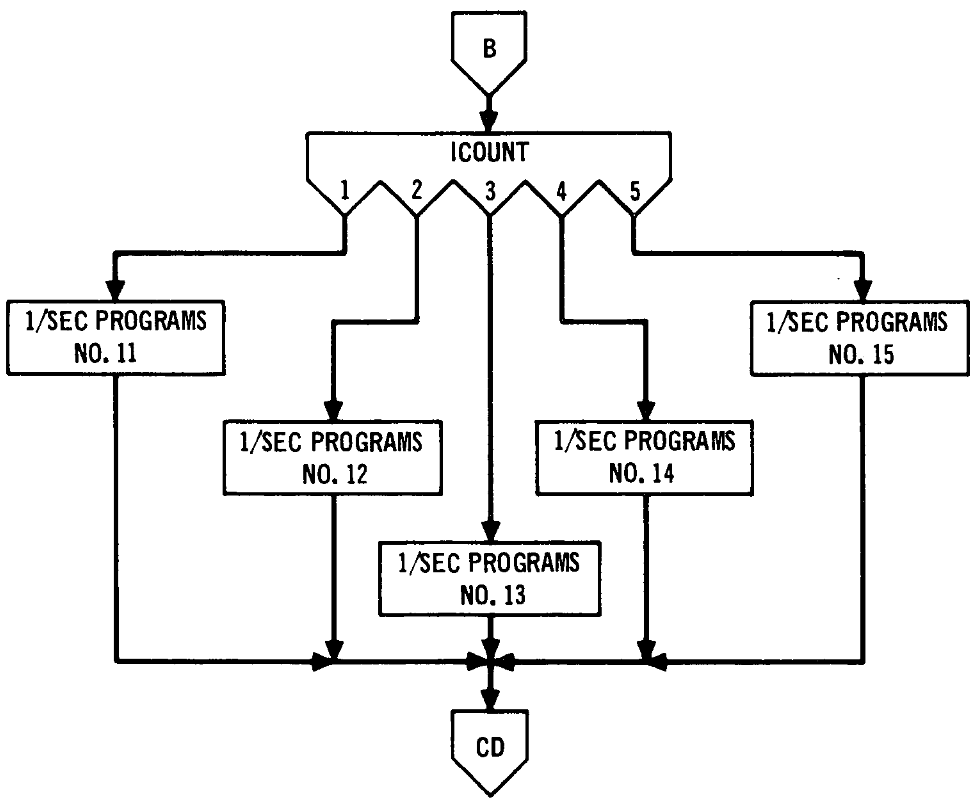
Throughout the discussion of the software package, references to CRT's and keyboards will be according to the numbering shown in Figure 4.3-7. In some sections a keyboard and CRT combination are referred to as a console according to the definitions in the figure.



CALLING SECTION OF EXECUTOR ROUTINE

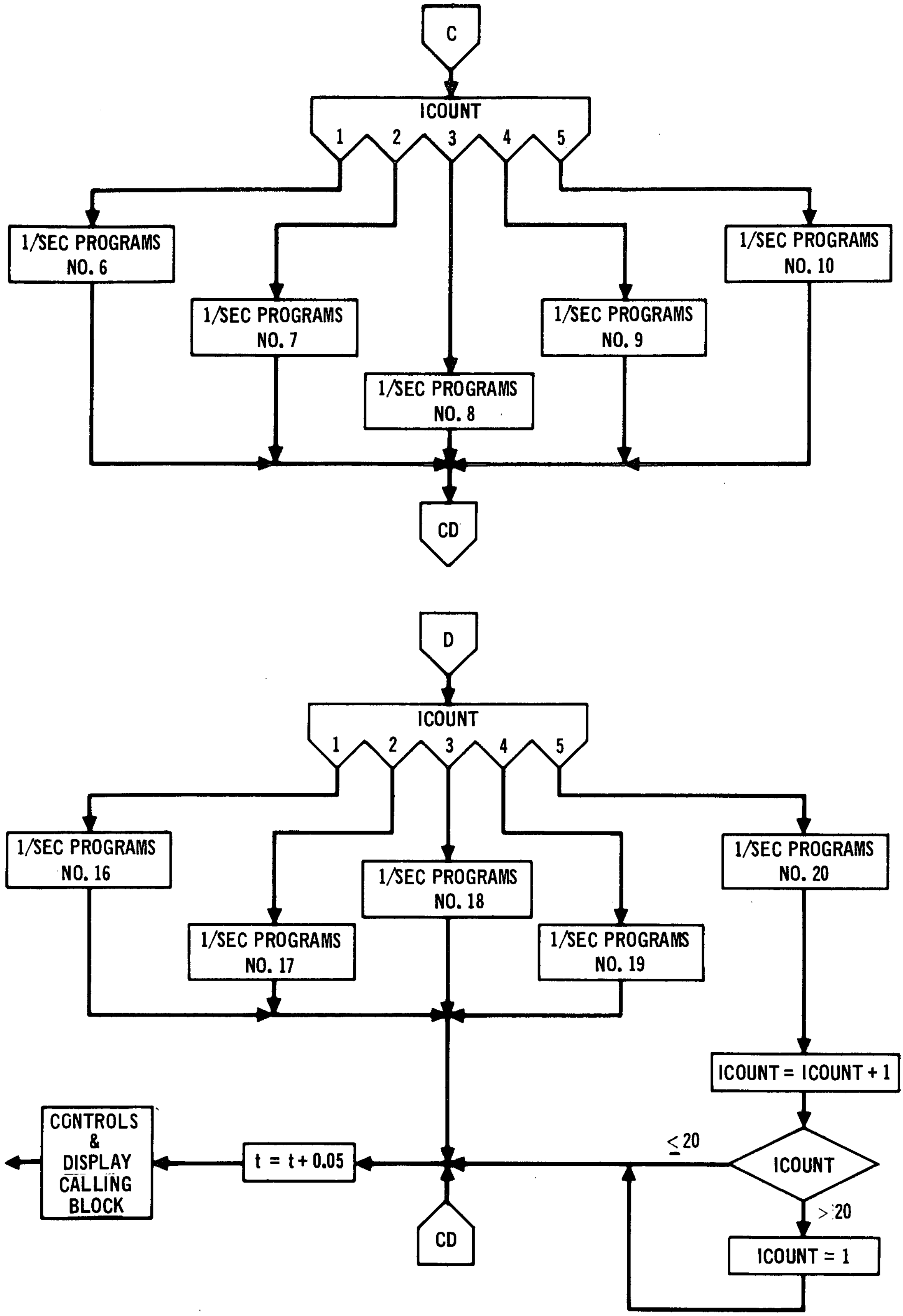
Figure 4.3–5





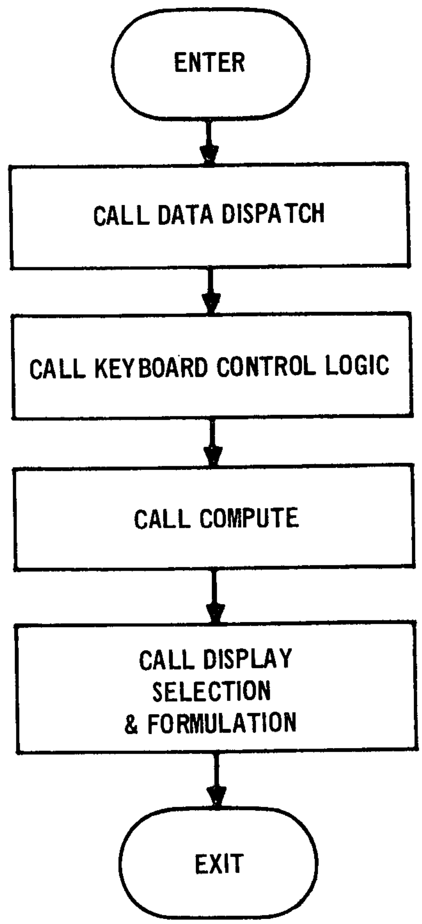
CALLING SECTION OF EXECUTOR ROUTINE (Continued)

Figure 4.3–5



CALLING SECTION OF EXECUTOR ROUTINE (Continued)

Figure 4.3–5



D & C SUBROUTINE CALLING ORDER

Figure 4.3–6

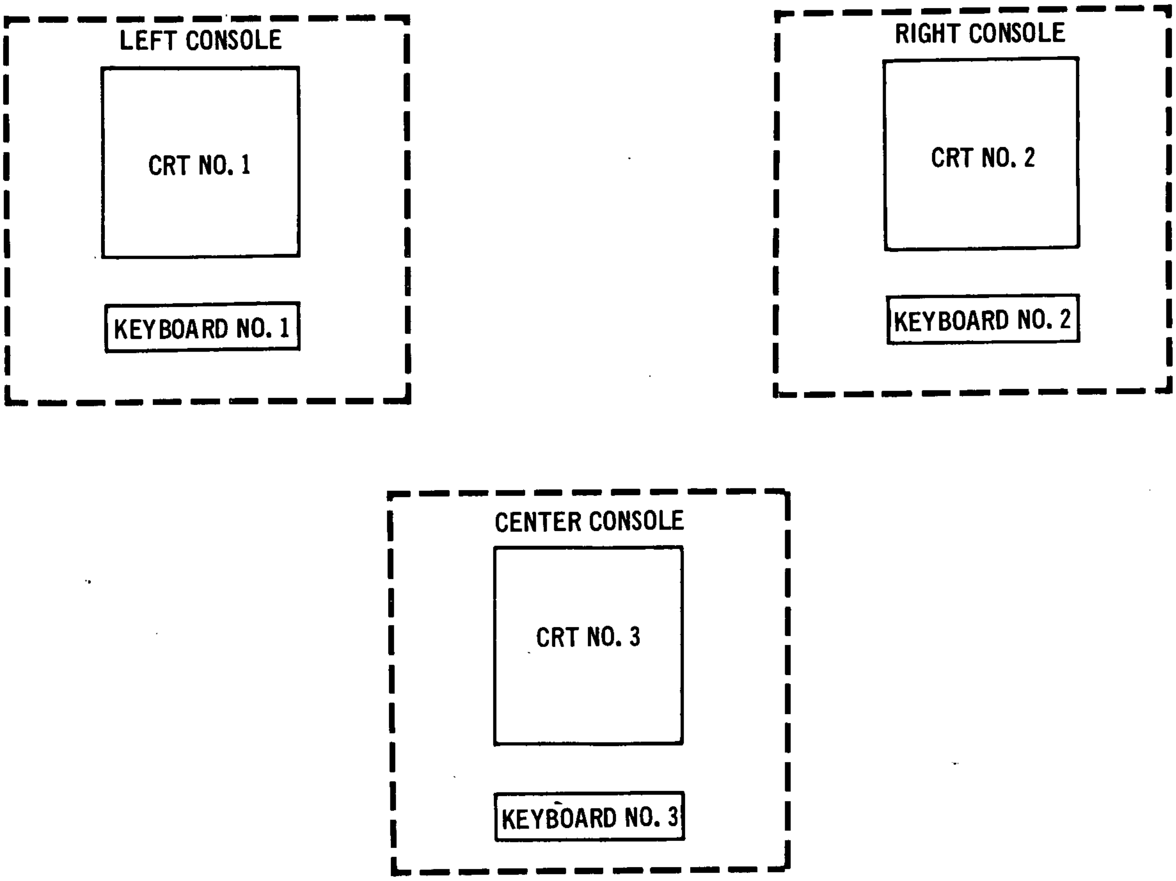


DIAGRAM SHOWING NUMBERING
OF CRT'S AND KEYBOARDS

Figure 4.3–7

4.3.1.5.1 Routines Comprising the C&D Software Package

4.3.1.5.1.1 Data Dispatch - The data dispatch system consists of a data dispatch switch panel in the crew station interfaced with a data dispatch software routine in the digital computer. The function of the system is to provide the crew with a capability to change the control and display functions from one console (keyboard and CRT combination) to either one or both of the other consoles. Once a display is called on one console, using the normal calling procedures, it may be dispatched to another by depressing an appropriate switch on the panel; thus eliminating the necessity for repeating the calling procedures to obtain the same display on two or more CRT's.

The system also provides the pilot and copilot with the capability to interchange displays by depressing a single switch on the panel.

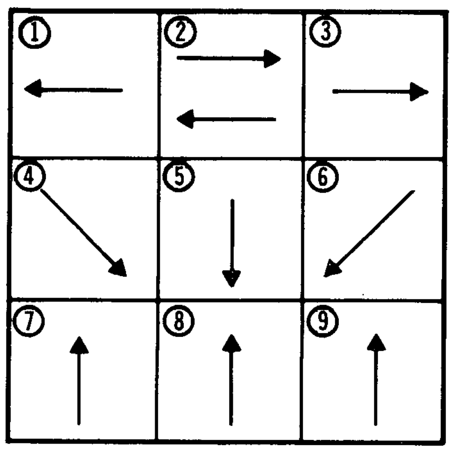
A summary table showing the functions requested by each switch is given in Figure 4.3-8 which also presents a diagram of the dispatch panel showing reference switch numbering. For example, if switch 1 is depressed the display presently on the right console is requested for the left console also. In addition, any inputs originating from the left keyboard are to be handled as if they originated from the right keyboard. The display on the left console at the time of the switch depression is saved for restoration when the switch is deactivated. In addition, illumination of the switches on the panel is provided to inform the crew as to which functions are active. It can be noted from the table that switch 2 results in an interchange of the control and display of the left and right consoles. Saving the display is not required for switch 2 since a second depression will restore the control and display to the current configuration. Also, switch 2 illumination is not required since interchange action always occurs when switch 2 is depressed.

The action described in Figure 4.3-8 for switches 1, 3, 4 and 6 is taken when the requested functions are not already active. If the functions are active when the switch is depressed, they will be deactivated (the switch illumination will be extinguished and the saved display will be recalled).

A functional diagram of the software required in the data dispatch system is shown in Figure 4.3-9. The software communicates with the crew station panel through two (one input and one output) discrete channels in the interface unit. Depressing a switch on the panel results in setting an assigned bit on the input channel. The bit will remain set as long as the switch is held in the depressed

SWITCH	COMMANDS					
	ILLUMINATE SWITCH	ASSIGN DISPLAY		ASSIGN INPUTS		SAVE DISPLAY
		ON	TO	OF	TO	ON
1	1	R	L	L	R	L
3	3	L	R	R	L	R
4	4	L	C	C	L	C
6	6	R	C	C	R	C
2	NOT ILLUMINATED	INTERCHANGE R&L; MAINTAIN INDEPENDENT CONTROL				NO SAVE

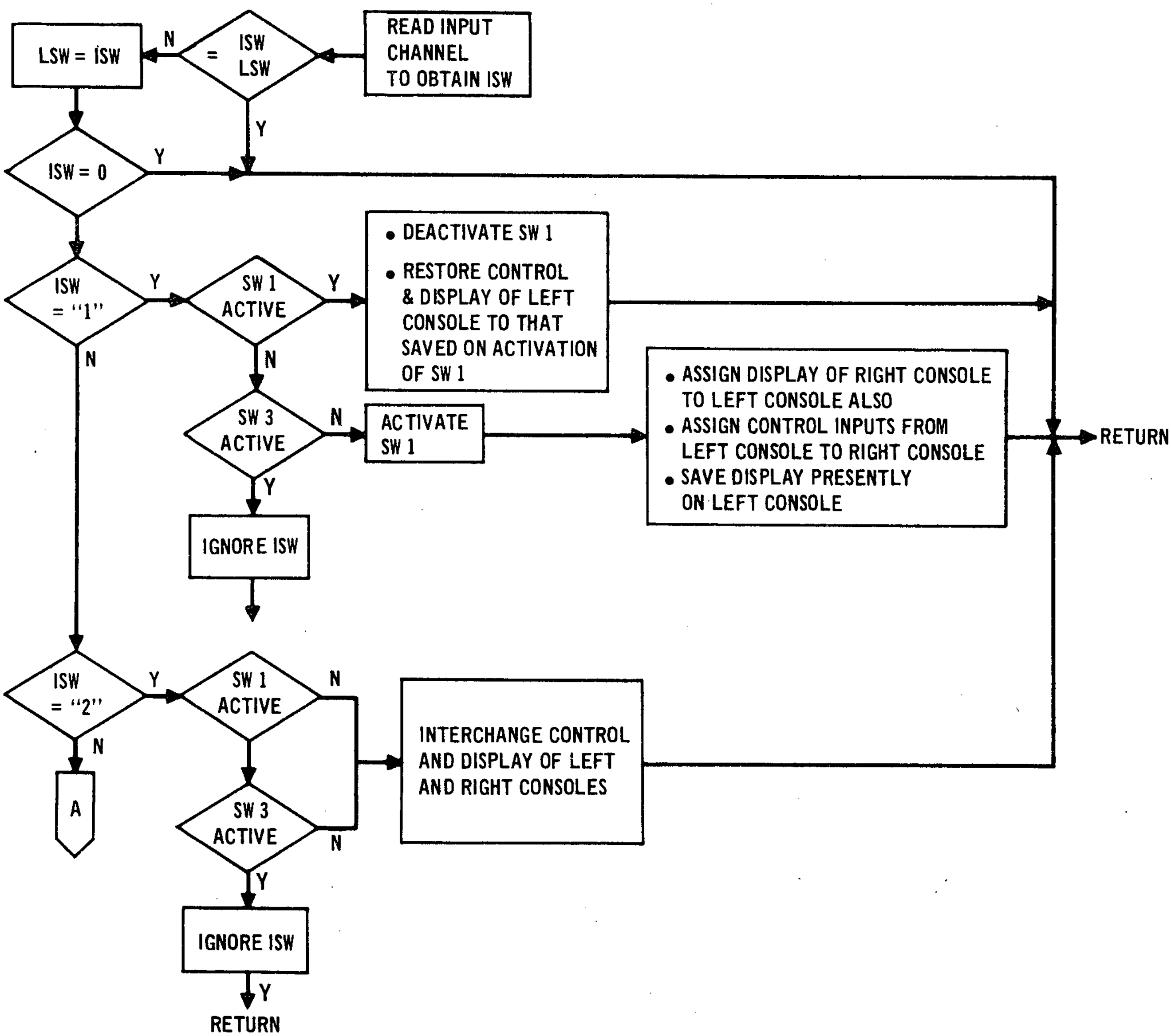
R – RIGHT CONSOLE L – LEFT CONSOLE C – CENTER CONSOLE



DATA DISPATCH PANEL

DATA DISPATCH COMMAND FUNCTIONS

Figure 4.3–8

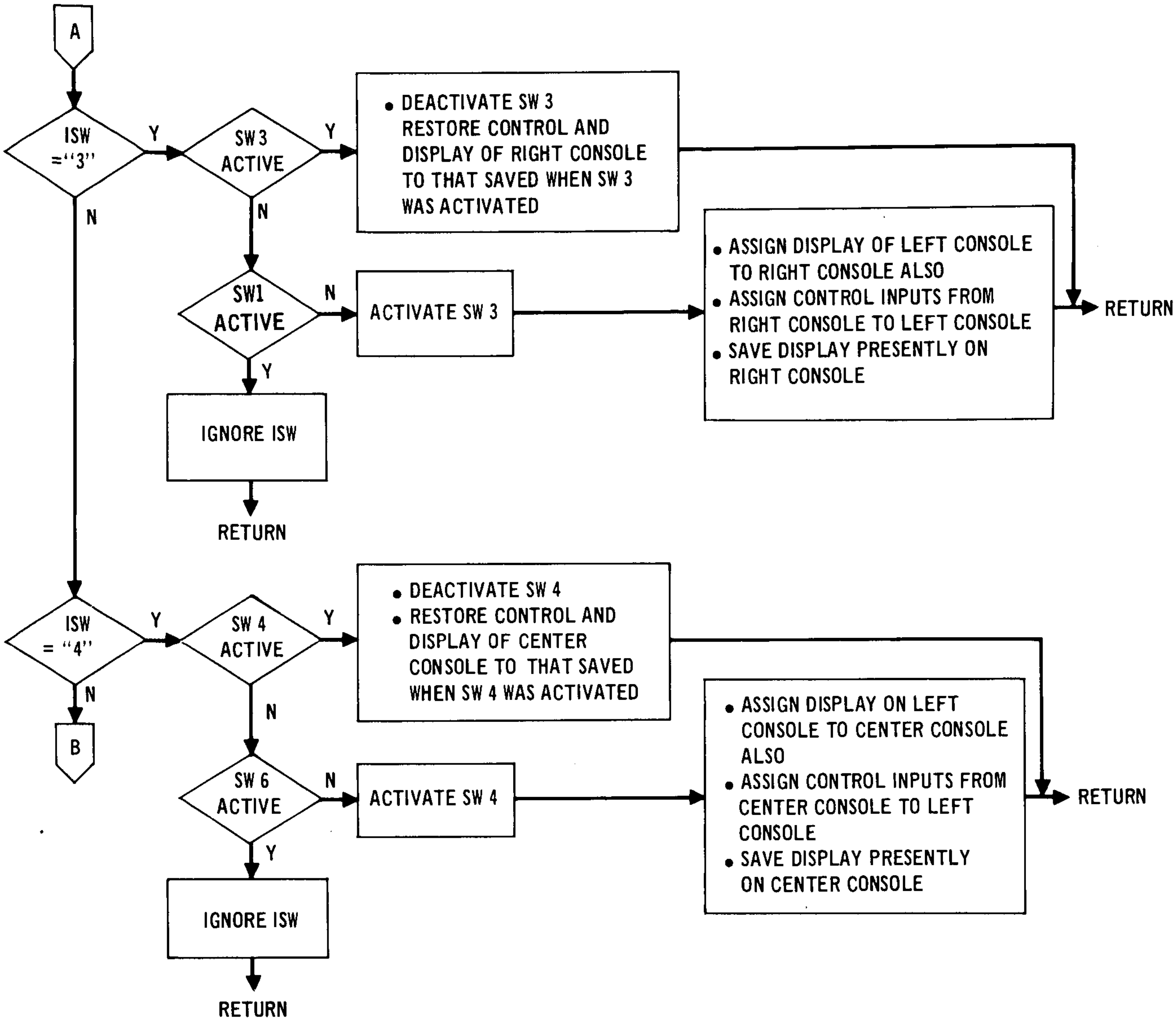


SYMBOLS

ISW	NUMBER OF THE SWITCH THAT HAS BEEN DEPRESSED (OBTAINED ON THIS READ).
LSW	NUMBER OF SWITCH DEPRESSED ON LAST READ (50 MILLESECONDS PREVIOUS TO THIS READ)
SWJ	SWITCH NUMBER "J"

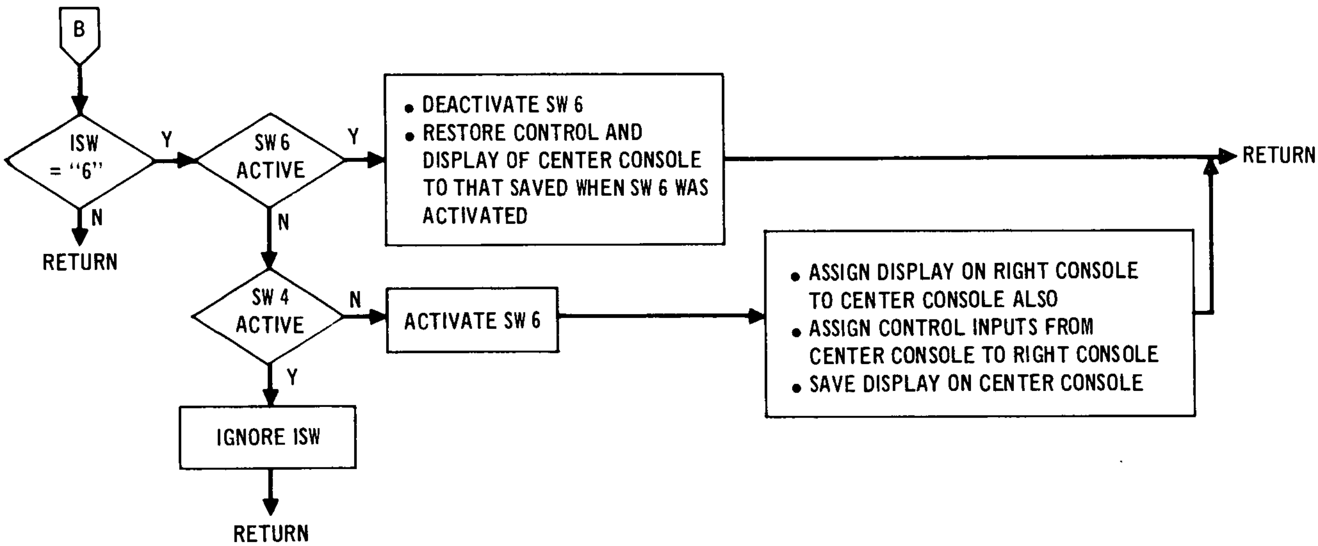
DATA DISPATCH ROUTINE

Figure 4.3–9



DATA DISPATCH ROUTINE (Continued)

Figure 4.3–9



DATA DISPATCH ROUTINE (Continued)

Figure 4.3–9

condition and will reset to "0" when the switch is released. The software interrogates the input word 20 times per second; therefore, it is possible for the bit to be "HI" on two successive passes. It is necessary to compare the present input word with the previous input word to prevent repeated activation and deactivation of a commanded function on the same switch depression. A switch must be released and depressed again before a second action is taken. If the input word is zero, none of the switches have been depressed and action is not required.

Upon sensing a bit to be "HI", the software identifies the depressed switch by the position of the bit in the input word and makes a check to determine if the request associated with the switch is currently active. If the result of this test is negative ,further testing is conducted to determine if the request can be granted. Switches 1 and 3 or switches 4 and 6 cannot be activated simultaneously; the switch 2 function request is not granted if switch 1 or 3 is active. If the request does not violate any of the above constraints the assignment of Figure 4.3-8 for the given switch depression is made. If the switch is currently active, the deactivation functions for that switch are performed. If the request cannot be granted the switch depression is ignored.

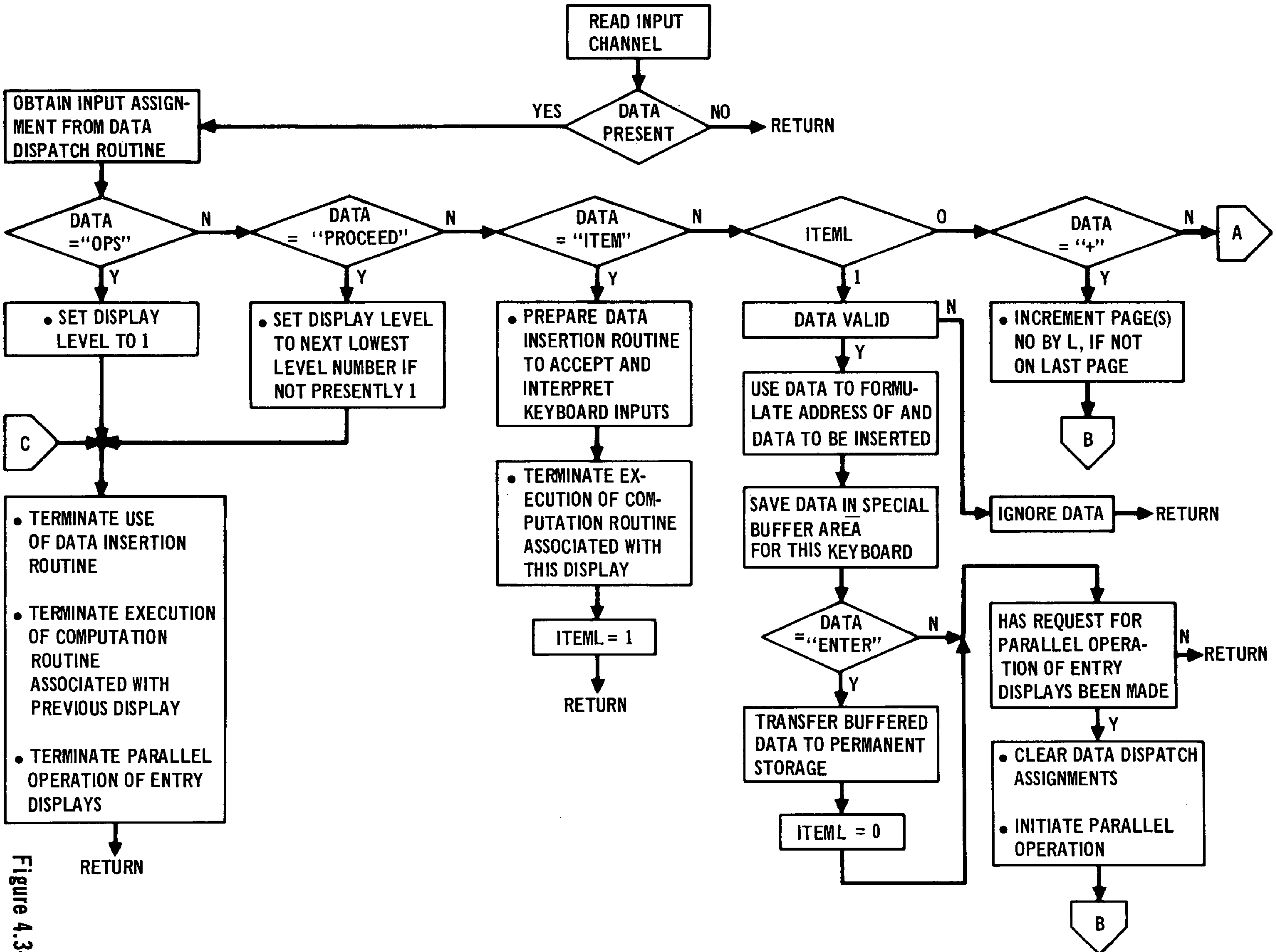
The output word consists of a bit pattern which is returned to the crew station via the interface unit where it is interrogated by the hardware to light or extinguish switch illumination.

4.3.1.5.1.2 Keyboard Control Logic - Display and computation control is provided through the use of 3 keyboards each containing 5 function keys, 10 numeric keys, 2 sign keys and a decimal key. The keyboards communicate with the keyboard control logic software package through a discrete channel in the crew station/digital computer interface unit, each keyboard being assigned to an individual channel. The depression of a key results in setting a 5 bit pattern on the discrete channel which the software uses together with the channel number to determine what key has been depressed on what keyboard and the response action to be taken. All three keyboard channels are read and processed at 50 millesecond intervals. The hardware provides for the resetting of the input word to zero after the read function is performed. The input channel will remain zero until another key is depressed.

It is the interpretation of the keyboard inputs by the keyboard control logic software which provides the capability to select displays, insert data into computer memory and execute specified computations or control commands.

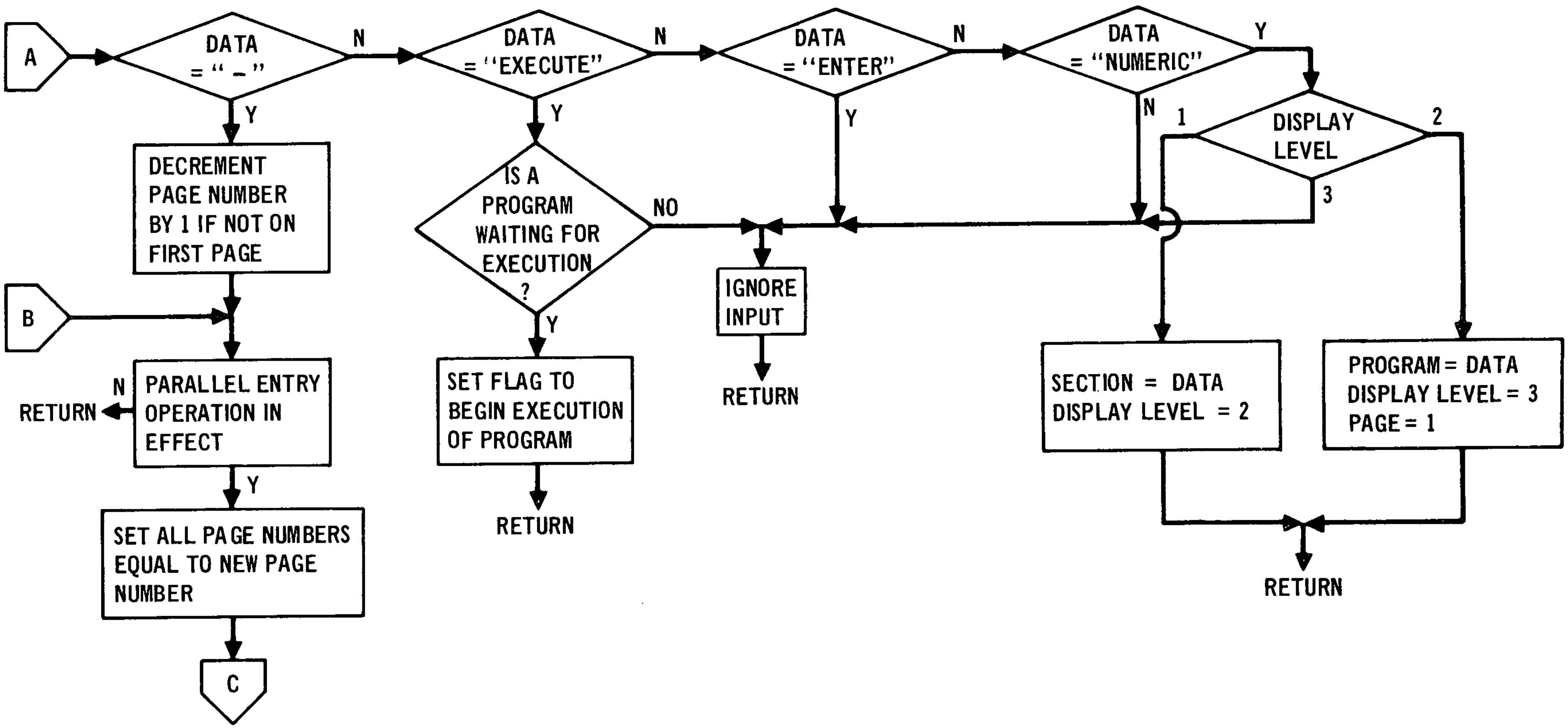
A functional block diagram of the keyboard routine is shown in Figure 4.3-10. The diagram is shown for only one keyboard for purposes of illustration. Extension to three keyboards is provided by subscripting the parameters required for proper operation of each keyboard. All data generated in the routine is stored by an effective keyboard number which may or may not be the same as the actual number depending on the data dispatch functions which are operative. (See data dispatch).

Referring to the diagram of Figure 4.3-10, it is seen that the software checks the input to determine if one of the function keys has been depressed or if the data insertion routine is being used (ITEML = 1). If the data insertion routine is not in use, the two sign keys are treated as functional requests. By the process of elimination, if none of the above tests are satisfied the input data must be numeric. However, one last test is made to check if the data is numeric. This test will have a negative result only in the event of a hardware malfunction. Numeric data is used to set the section or program number



KEYBOARD LOGIC CONTROL ROUTINE

Figure 4.3–10



KEYBOARD LOGIC CONTROL ROUTINE (Continued)

Figure 4.3–10

depending on the display level. For purposes of calling displays and associated computation routines, the computer software is considered to be divided into sections, programs, and subprograms. Referring to the calling procedures, the section is specified by selecting a category from the level 1 display (flight operations). The program is specified by selection of a category from the level 2 display. A subprogram is defined by the page number of the level 3 display (operational display). All level 3 programs begin with the page 1 display.

The response actions taken for a functional request are described on the diagram of Figure 4.3-10 and are for the most part self explanatory. It will be observed that execute commands and use of the data insertion routine are terminated if a display change takes place.

A few supplementary remarks concerning data insertion and parallel entry displays are in order at this point. When the ITEM key is depressed the data insertion routine is called into execution and initialization of the routine is made at this time. Execution of any computational program associated with the display is terminated since ITEM indicates a change in input data is desired. A logic parameter, ITEML, is set to direct future keyboard entries to the data insertion routine. The first two inputs following the initialization are used by the routine to identify the input parameter for which it is desired to insert data. If either of these inputs is not numeric, it will be ignored by the routine. If the item number is not found from the current display format data (illegal item number) the data insertion routine will reject further input data until the ITEM key is depressed and a new item number entered. If negative data is to be inserted, the sign must be entered as the third keyboard entry; failure to do so will result in treating the data as positive and ignoring the sign if entered on future entries since on these entries it is illegal. A decimal may be used any time after the first two entries, but a second decimal point is illegal and will be ignored. Repeated depression of the ITEM key and inserting the same or a new item number will allow correcting the inputs or inputing additional data respectively.

The data entered is stored in a special keyboard buffer area (one for each keyboard) in display code for display purposes and in binary for insertion in the program. When the ENTER key is depressed the stored binary data is transferred to permanent storage in an address identified by the item number. Termination of the use of the data insertion routine is made at this time.

The keyboard buffer area is interfaced with the digital data display routine (discussed in a later section) such that the following will occur:

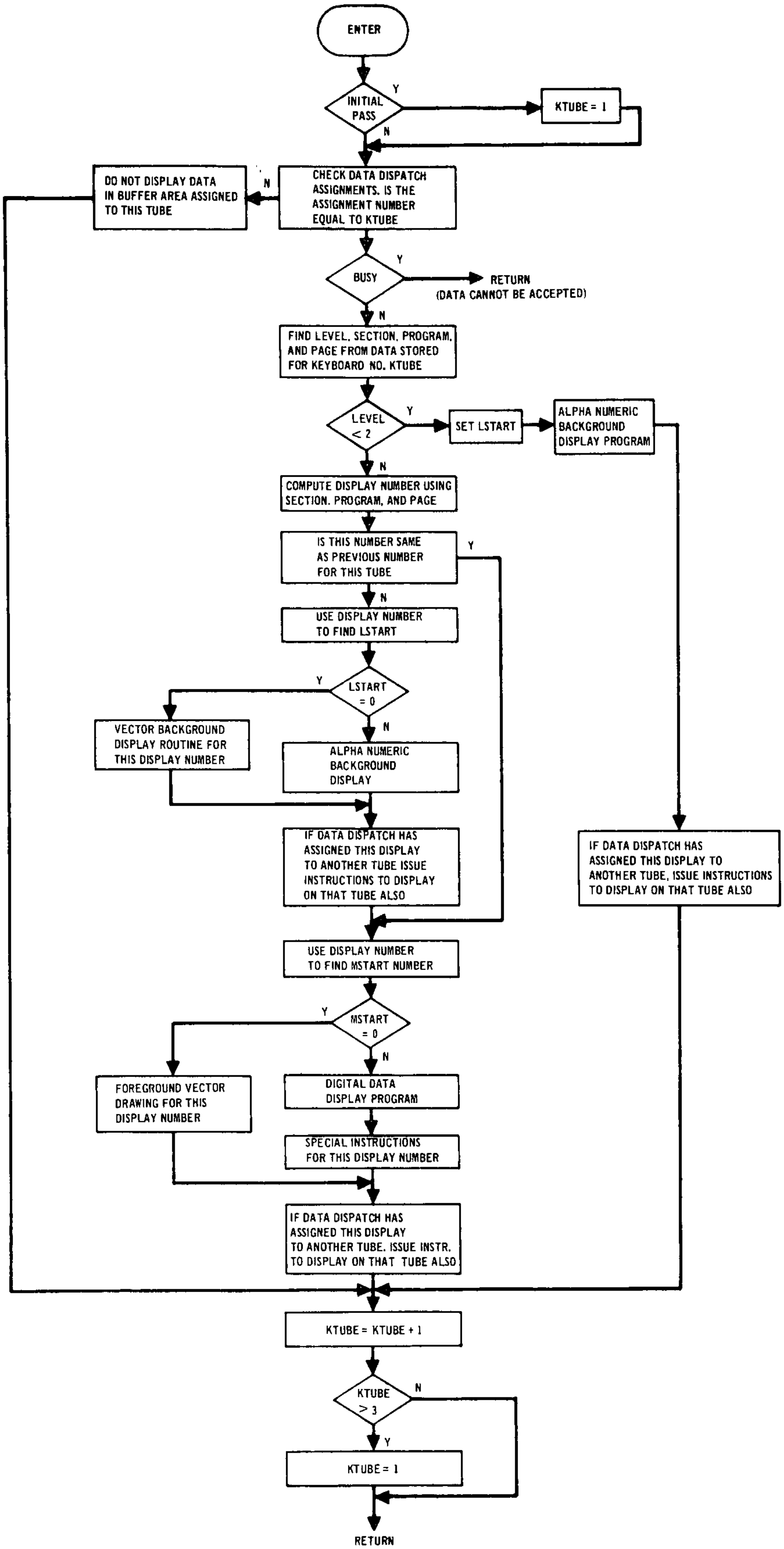
- As soon as the item number is identified the data displayed for the parameter associated with that number will be blanked on the CRT.
- As new data is being inserted, it will appear in the display slot as shifting in from right to left, one shift occurring for each number entered.

A parallel logic parameter is displayed on each page of the Return Sequence display branch number 36 (see Figure 3.3-1). The data insertion routine may be used to set the parameter such that parallel operation of the entry displays in branches 35, 36 and 37 is obtained. When this mode of operation is initiated all data dispatch assignments are cleared and the displays of branches 35, 37 and 36 are assigned to CRT's 1, 2, and 3 respectively. The page number for all displays will be that of the display from which the logic was set. Incrementing or decrementing of the page number of any display for one branch will result in corresponding page changes on the other two branches of displays. Once parallel operation in the three branches is obtained, the data dispatch functions are again available. Parallel operation will continue until the logic parameter is reset through use of the data insertion routine or an OPS or PROCEED command is received from a keyboard. In the latter case the display associated with the requesting keyboard will return to level 1 or level 2. The other displays will not be affected (unless of course through data dispatch operation).

4.3.1.5.1.2 Display Selection and Formulation - The display section performs 3 basic functions: 1) Selecting the CRT which is to be updated on a given pass through the routine, 2) Finding the display that is to appear on the CRT, and 3) Computing instructions for formulating the display. The performance of these functions are illustrated in the software functional diagram of Figure 4.3-11.

The display routine is entered 20 times per second which does not allow time for updating all three CRT displays on every pass. Only one display is updated on each pass. The display software maintains an account of what display is to be processed on each pass (KTUBE). Before exiting from the routine the CRT counter is updated by 1 and reset to one when the counter reaches a value greater than three. It is noted here that update is being used to refer to changes in the data on a display and should not be confused with display refresh rate.

Having the CRT number that is to be updated, the next function required is the determination of the display associated with that CRT. If the data dispatch functions are not operative, the software obtains the level, section, program and page, which has been stored from the keyboard control logic for the keyboard identified by the same number as KTUBE. If the level is less than two it is already known that the display is a fixed alphanumeric type and this display routine is called with an indicator (LSTART), informing the program where in the



DISPLAY SELECT ROUTINE FUNCTIONAL DIAGRAM

Figure 4.3–11

format data to start reading instructions for drawing the requested display. LSTART is set to 1 when the level is 1 and is a function of the section number when the level is 2. The fixed alpha-numeric display routine is discussed in Section 4.3.1.5.2.1.

If the level is greater than three the software computes the display number and checks to determine if it is the same as the previous number for the CRT being updated. If it is not the same, a new background display must be formulated. The background display consists of those portions of the total display which are fixed as to position and intensity on the display area. Once the computations and instructions are performed for this display they are stored in a buffer area associated with the CRT on which they are displayed and need not be repeated. This is advantageous from a time saving standpoint. The background display may be an alphanumeric and/or a graphic type (vector drawing). If the latter, a vector drawing routine for the particular display is used.

Similar logic is used in drawing the foreground display (display of dynamic elements in the display), and this logic is called each pass through the routine. The data is stored in the same buffer area as the background data. The digital data display routine is discussed in Section 4.3.1.5.2.2. In some instances when using the general digital data display routine special instructions may be required which are unique to a certain display such as drawing lines to partition the display area or setting certain logic parameters. An instructions area is provided for each display of this type.

In addition to the above method of selecting a display number based on level, section, program and page, the display software interfaces with the data dispatch routine. When the data dispatch assigns a display from one CRT to another, the display routine notes the assignment and issues instructions to switch the CRT from its display buffer area to the buffer area assigned by data dispatch.

4.3.1.5.2.1 Alpha Numberic Background Displays - The alpha numeric background display routine accepts information from the display format data array labeled INFORMB in Figure 4.3-12. This array consists of a number of 60 bit data words which inform the display routine as to what messages are to be displayed. The packing of the data in a 60 bit word causes some increases in computer time which is counteracted by a reduction in computer core requirements.

INFORMB ARRAY

NCHAR	MESSAGE NO.	ITEM	COLUMN	LINE
⋮	⋮	⋮	⋮	⋮

ALPHA NUMERIC

INFORMD ARRAY

NDEC	NCHAR	COLUMN	ADDRESS	ITEM	LINE
⋮	⋮	⋮	⋮	⋮	⋮

DIGITAL DATA FORMATS

VECTOR DRAWING ROUTINES

VECTOR BACKGROUND FORMATS

DEFINITIONS: LINE and COLUMN: The display area is divided into 12 horizontal partitions and 48 vertical partitions referred to as LINE and COLUMN respectively.

MESSAGE NUMBER: This number identifies a particular message from an array of messages that is to be written on LINE starting at COLUMN.

NCHAR: This number informs the display routine as to the number of characters contained in the message to be written.

ITEM – INFORMB : Signifies that the data associated with the following message is capable of being inserted through the use of the data insertion routine. Data is typed in using the item number.
INFORMD : Item is included here for an ITEM search to obtain the position on the screen at which to display data insertion entries.

ADDRESS – The address associated with item identifies the location in computer memory where the inserted data is to be stored or where data to display is located.

NDEC – Specifies the number of characters to the right of the decimal point which is desired for the display of digital data.

DISPLAY DATA FORMATS

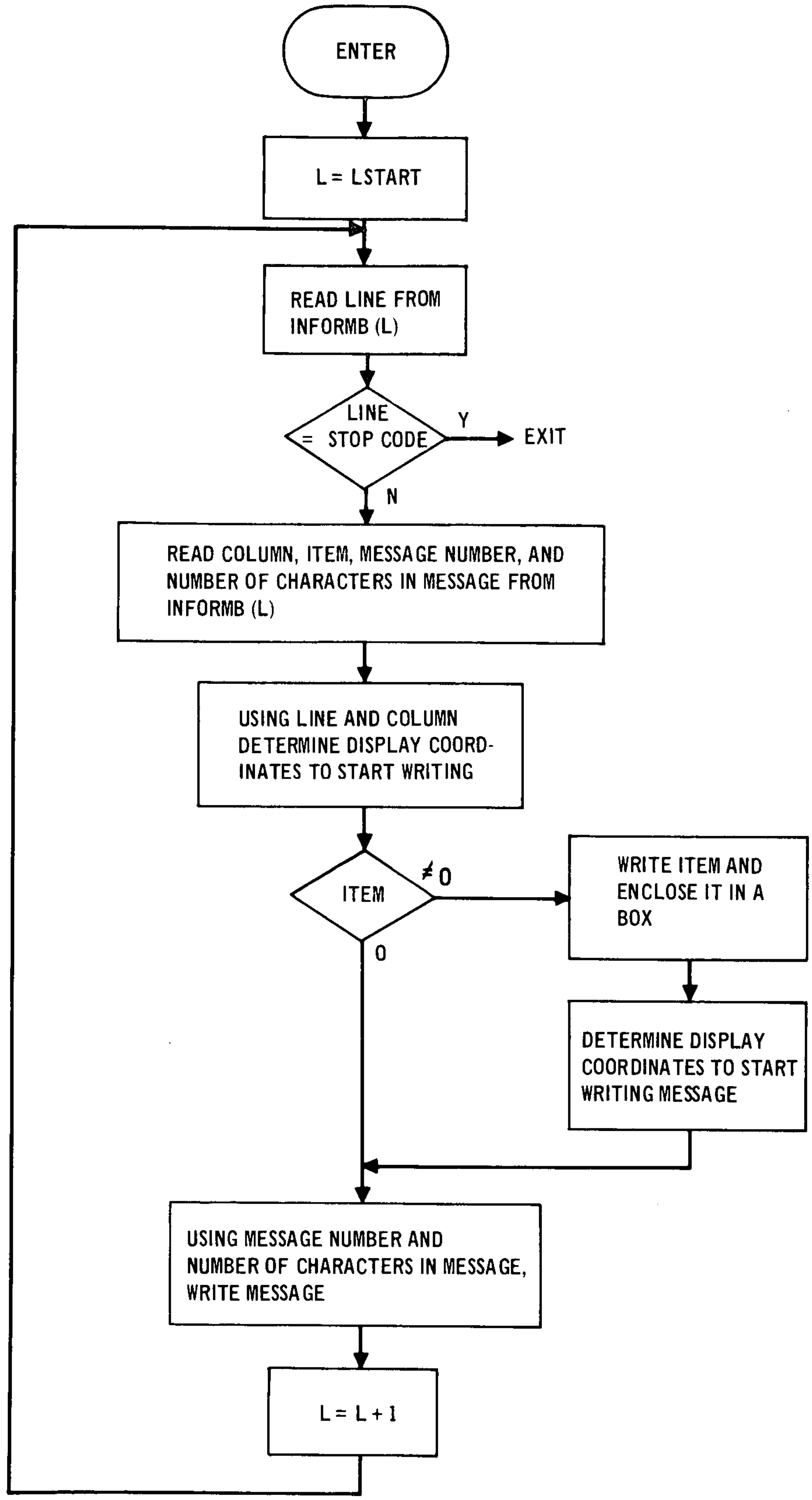
Figure 4.3–12

A general routine used for formulating all alphanumeric background displays is shown in Figure 4.3-13. The routine reads the INFORMB array starting at LSTART (set in display selection) and uses the data together with the graphics library to perform the display generation instructions shown in the routine. If more than one message is desired on a given line of the display an INFORMB word must be included for each message desired. The line number entered for each of these words would be identical. Since the data format array may vary in length from one display to another, a stop code is used as the last word in a section to inform the routine that the display generation is complete.

4.3.1.5.2.2 Digital Data Displays - An array similar to that of INFORMB is used in generating the digital data displays. This array is referred to as INFORMD in Figure 4.3-12. This array contains the same positioning data as INFORMB. In addition, data is provided to inform the routine as to the location in computer memory where the digital data to be displayed can be found. Information as to decimal formatting of the displayed data is also provided.

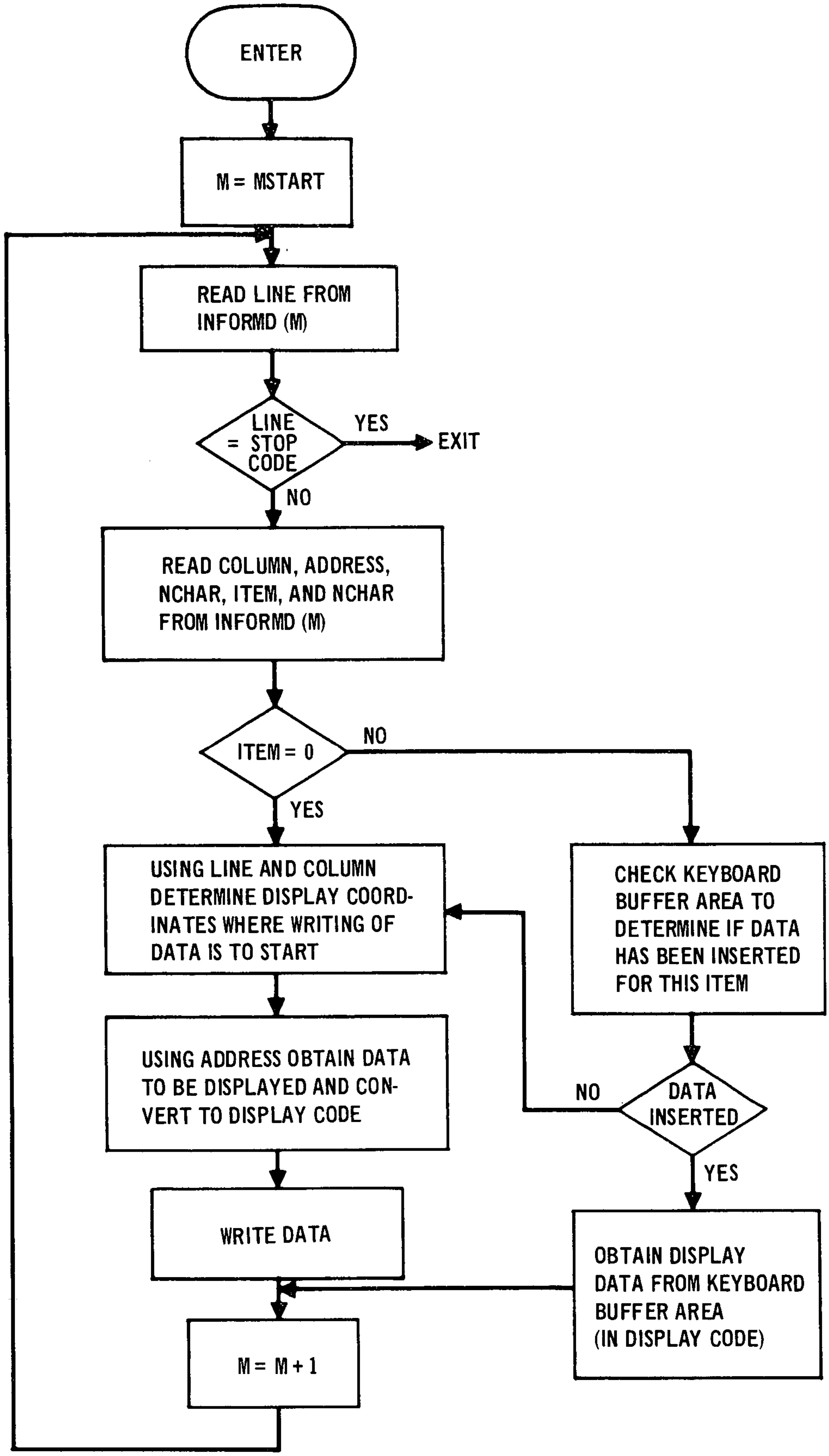
The routine for digital data display, shown in Figure 4.3-14 is similar to that used for the alphanumeric background displays, the basic difference is what is displayed.

An additional feature of the digital display routine is the display of data being inserted through the data insertion routine. As the routine scans the INFORMB array it tests to determine if data can be inserted on a given line. If it finds that data may be inserted it checks the keyboard control buffer area to determine if data has been inserted and displays the inserted data (if any) instead of the computer memory data.



ALPHANUMERIC BACKGROUND DISPLAY ROUTINE

Figure 4.3–13

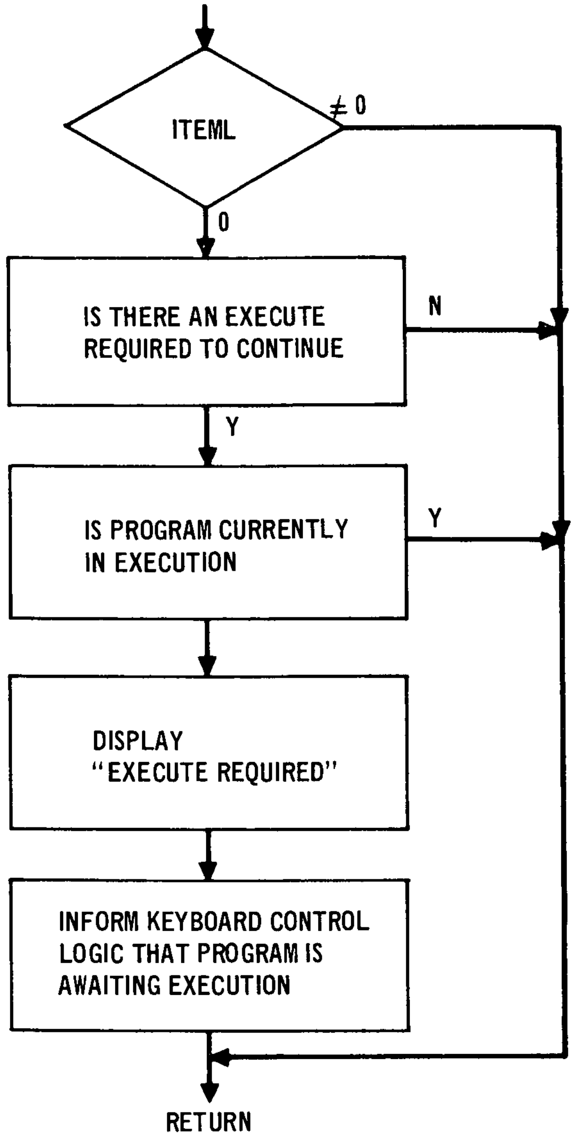


DIGITAL DATA DISPLAY ROUTINE

Figure 4.3–14

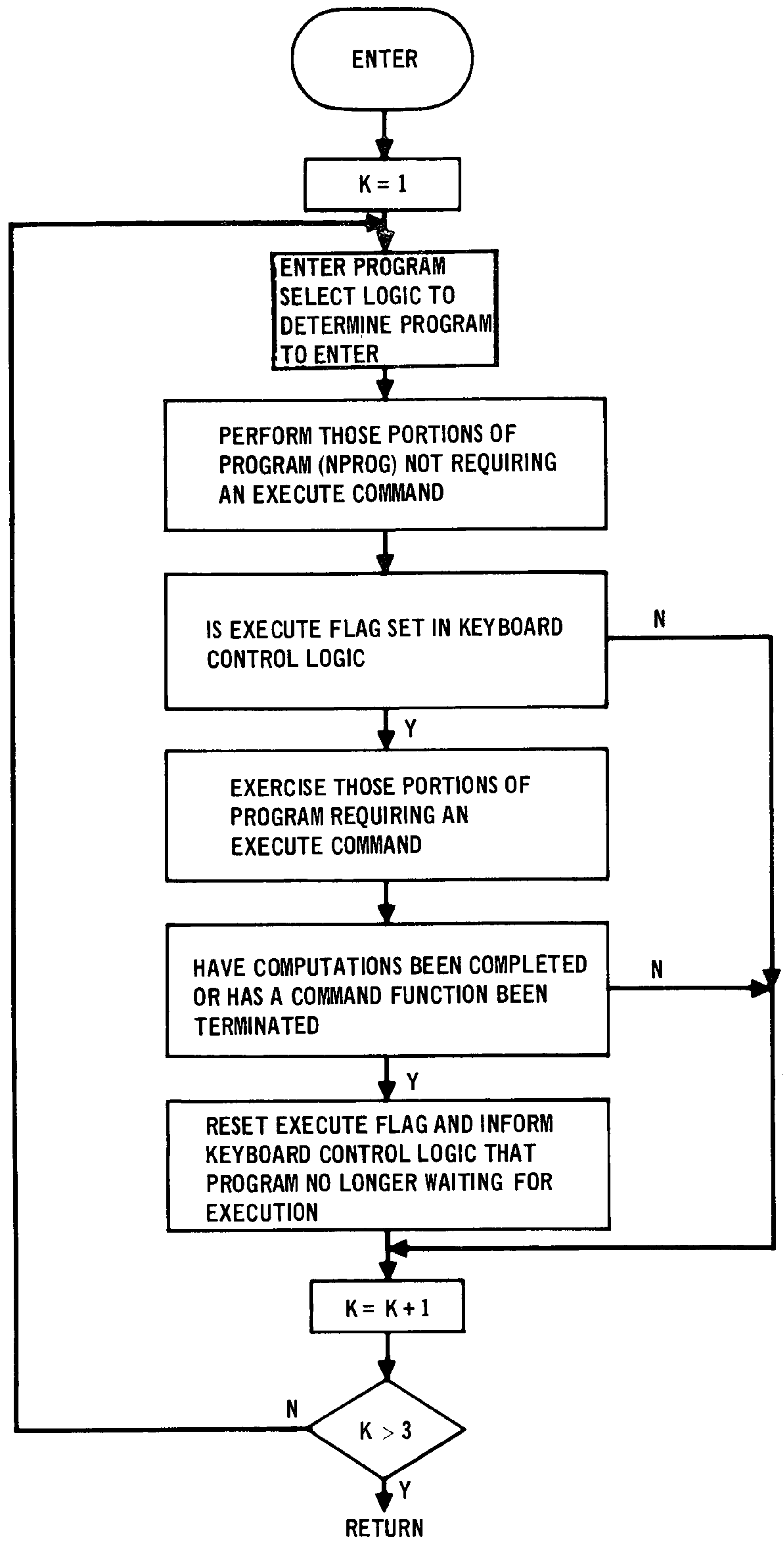
Exit from the digital data display, as previously stated, is to a special instruction block. One such block results in the performance of the instructions shown in Figure 4.3-15. The particular block that is shown reflects some of the control and display philosophy of this study. In those instances where a display and computation program or control command are directly related it is necessary that the crew be informed that an EXECUTE must be entered via the keyboard to compute display data or execute a control command. It is also necessary to inform the keyboard control logic that a program is awaiting execution so that the execute command from the keyboard is acknowledged. The interaction of the keyboard control logic, display selection logic and this routine makes it impossible to execute a command for which the display is not active.

4.3.1.5.3 Compute (execution of commands to the computer) - It is required to provide the crew with a keyboard command/control capability. The ground rule for providing this capability is the keyboard command/control capability cannot be exercised without the display. The software controls section which is presented in Figure 4.3-16 is designed to service this requirement. The program entered is coordinated with the display on the CRT by using the same logic for selecting the program number as is used for selecting the display number. If a display such as level 1 and level 2 displays have no computation requirement associated with it, the program instruction for that display will simply be an exit from the program. In general, the functions performed in this routine are described in the diagram. These functions are elaborated in the illustration shown in Figure 4.3-17. The display numbers in the illustration are those for Retro shown in Figure 3.3-1.



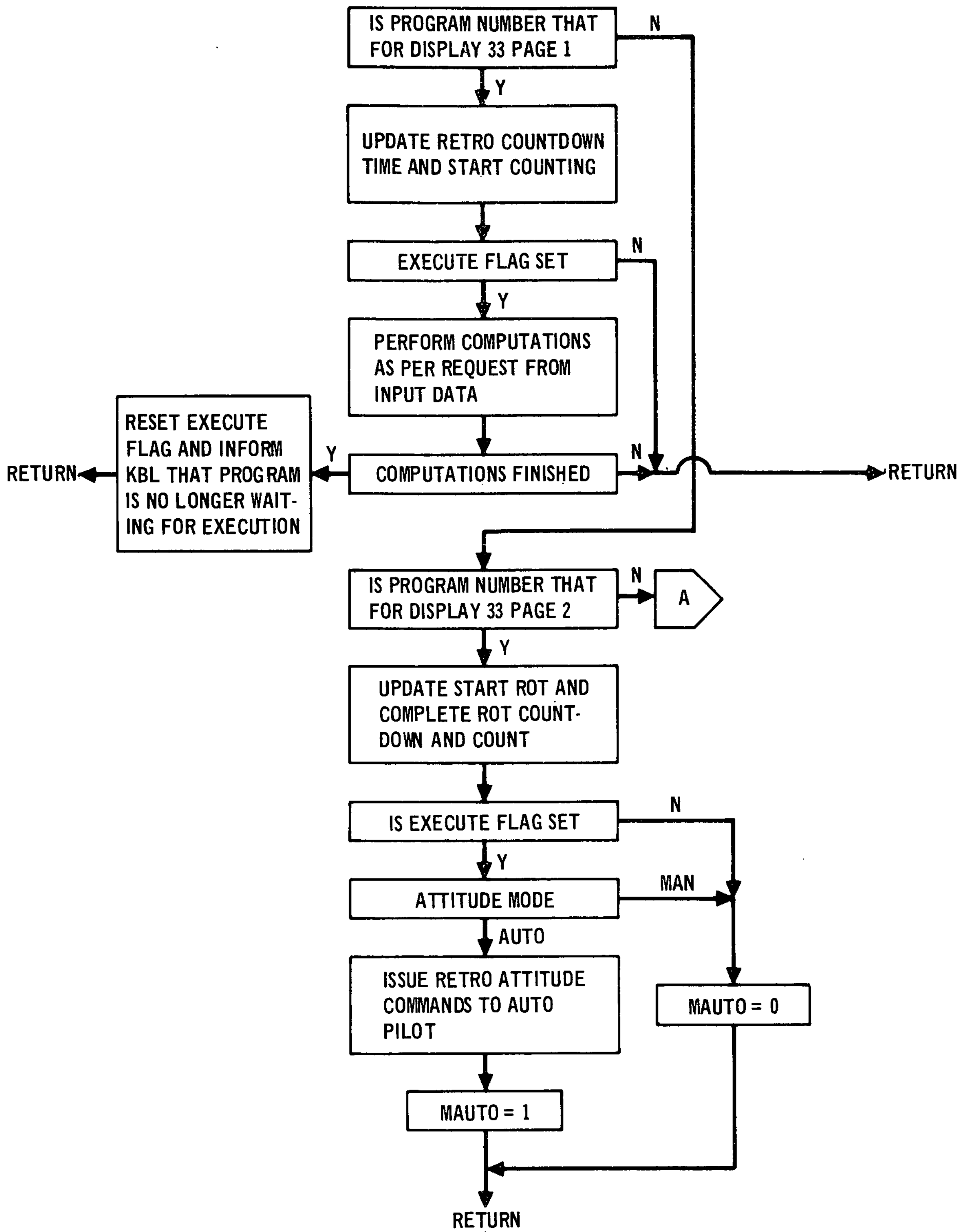
SPECIAL INSTRUCTIONS BLOCK

Figure 4.3–15



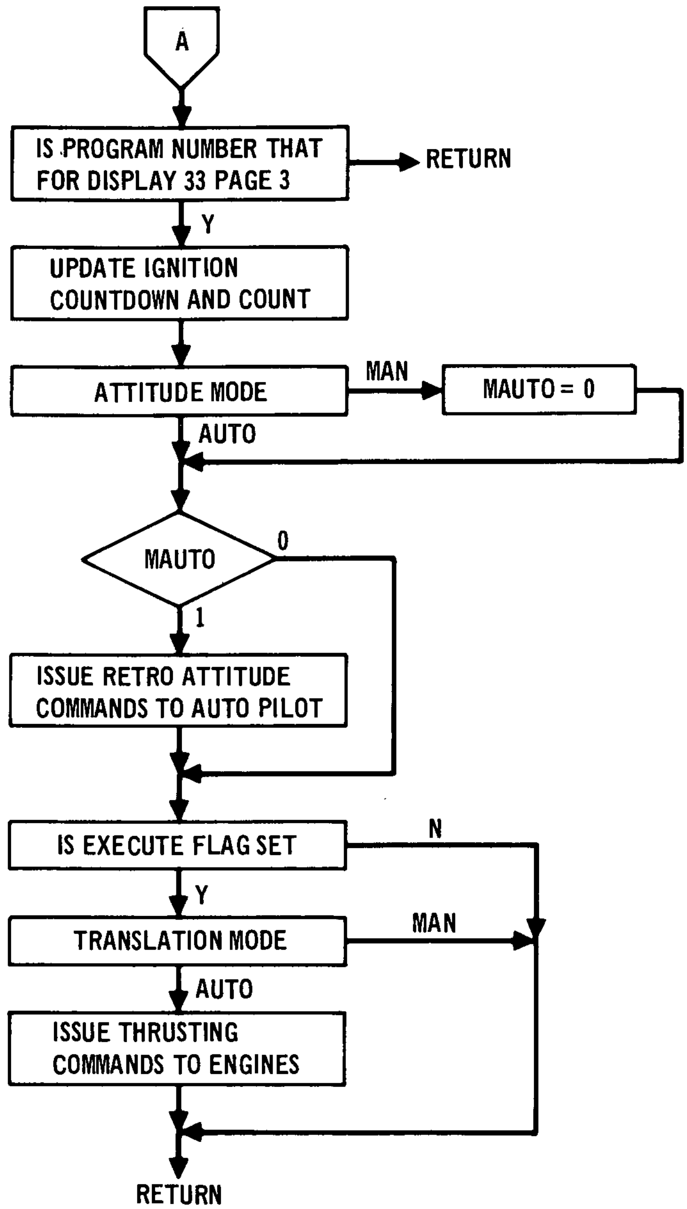
SOFTWARE CONTROLS SECTION BLOCK

Figure 4.3–16



PROGRAM SERVICING RETRO DISPLAYS

Figure 4.3–17



PROGRAM SERVICING RETRO DISPLAYS (Continued)

Figure 4.3–17

It can be noted that if display 33 page 1 is on a CRT,the retro time countdown procedes regardless of the EXECUTE command. However, to perform computations with requested input data, an EXECUTE command must be given from the keyboard. When the computations are finished the EXECUTE command flag is reset and the keyboard control logic notified that the program is completed.

At this time it should be recalled that the special instructions block in the display routine will notify the keyboard logic that the display is still active and the EXECUTE function may again be exercised. If it is desired to update the computations at a later time (with or without the same insert data),the EXECUTE function will again be permitted.

When leaving this display,all computations cease including the countdown. Therefore, it is necessary upon re-entering the computation program to update the countdown time and the state vectors before updating the display.

If the display 33 page 2 is on a CRT,the retro attitude control functions are provided by the corresponding program shown in the figure. In this program the function provided by the EXECUTE command is the initiation of the retro attitude rotation in the AUTO mode. Even though the countdown has reached "zero" and the attitude mode switch is in the AUTO position,initiation of the attitude maneuver will not occur until the EXECUTE command is issued. If the attitude maneuver is commenced, a flag (MAUTO) is set to inform the program for display 33 page 3.

Since the attitude maneuver is monitored on display 33 page 3 as well as 33 page 2 it is allowed to continue even though the display has changed. It should be noted however, that the automatic maneuver cannot be initiated from 33 page 3. If the attitude mode is changed to manual in this program, a return to display 33 page 2 must be made to reinitiate the automatic maneuver.

The EXECUTE key in the 33 page 3 program is used to commence thrusting if the translation control mode is in the auto position. As with the program 33 page 1, when leaving the latter two displays all functions provided in the program cease. To re-initiate translation with the EXECUTE key, it is necessary to return to display 33 page 3 and re-issue the EXECUTE command.

In summary, command/control functions may be initiated from the keyboard when the pertinent display is shown on the corresponding CRT. Countdown is displayed for crew information only and will not initiate a command/control function automatically. Commands/controls require deliberate action by the crew. Any maneuver operation which is to be initiated from the keyboard must have the following factors present:

- o The appropriate display must be showing.
- o The appropriate mode must be selected.
- o The EXECUTE key must be depressed on the keyboard which corresponds to the display.

Any maneuvering operation which has been initiated from the keyboard stops if:

- o The maneuver is completed.
- o The display is changed by PRO or OPS keys
- o The mode is changed

In certain cases, another display page can be obtained with the + or - keys and the maneuvering operation is allowed to continue if the monitoring information is still present.

4.3.2 Vehicle Simulation

4.3.2.1 Simulated Configuration - The vehicle simulated for this study is a high crossrange, fully reusable, orbiter developed during the NASA Phase B study. This configuration is depicted in Figure 4.3-18 while pertinent physical characteristics are presented in Figure 4.3-19. The physical data will be used throughout the flight regime and weight variations as a function of mission time will not be considered in this study.

Aerodynamic data for a Mach number envelope from M = 0.26 to M = 27 have been incorporated in the simulation. The wind tunnel and theoretical aerodynamic data from which this simulation was developed are summarized in Figure 4.3-20. The aerodynamic data were inputs to the simulation in tabular form with linear interpolation between input points. The equations for simulating total aerodynamic force and moments acting on the vehicle are shown in Figure 4.3-21.

Summary plots of the longitudinal characteristics are shown in Figures 4.3-22 through 4.3-34. Trim characteristics for the subsonic, transonic, and supersonic flight conditions are presented in Figures 4.3-22 through 4.3-24. The effect of landing gear on the low speed lift to drag ratio is shown in Figure 4.3-25. The influence of ground effect on the lift, drag and pitching moment coefficients is presented in Figures 4.3-26 through 4.3-28. The effect of Mach number on the incremental drag due to speed brake deflection is indicated in Figure 4.3-29. Hypersonic trim characteristics are shown in Figures 4.3-30 through 4.3-34.

A detailed description of the aerodynamic characteristics employed in this simulation can be found in Reference A.

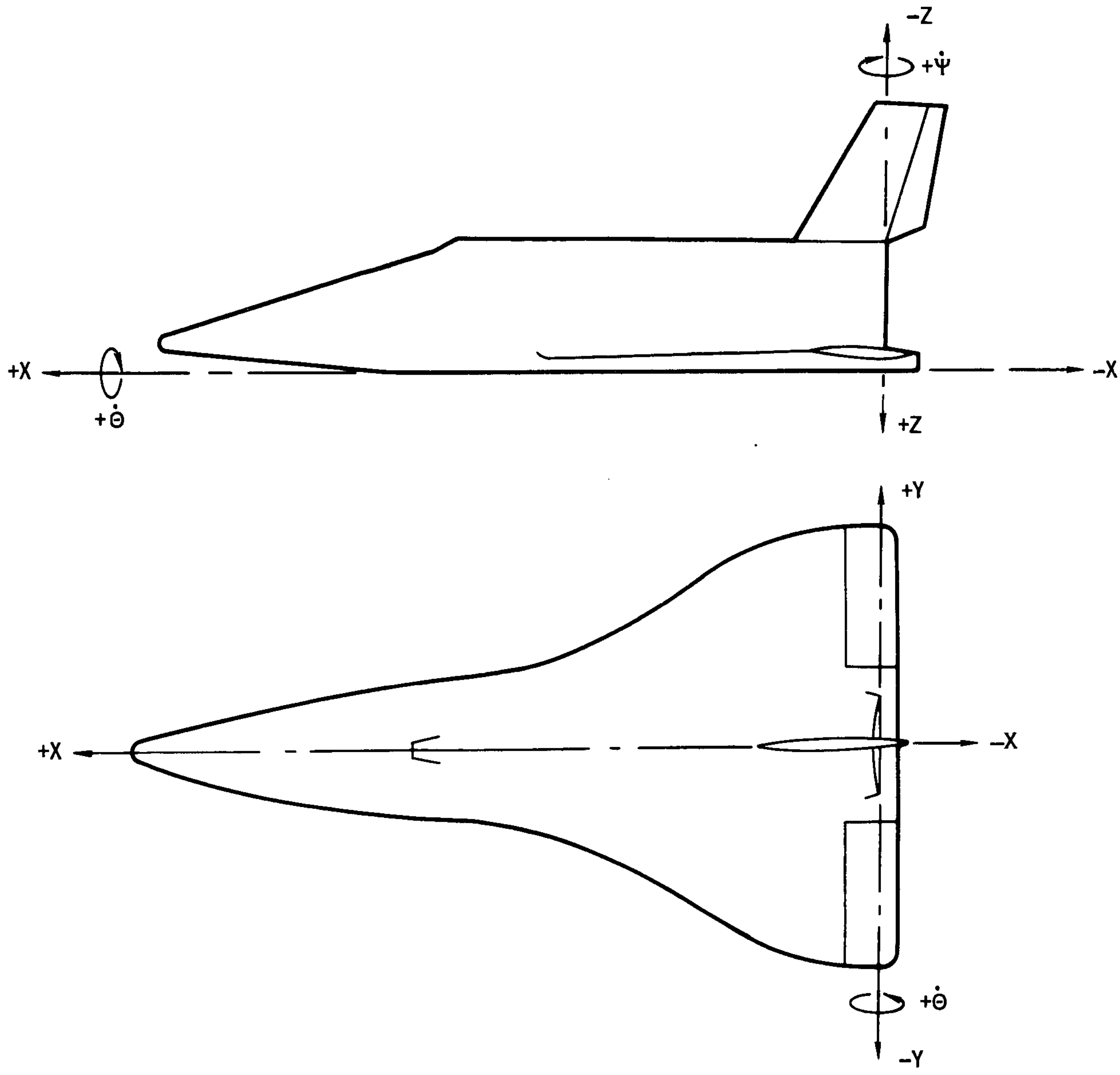
The atmosphere used in the simulation is the 1962 Standard atmosphere and is defined from sea level to 400,000 feet. Various wind profiles are also available for use and these profiles are shown in Figures 4.3-35 and 4.3-36.

A Reaction Control System (RCS) is used exclusively for attitude control in the on-orbit flight phases and is blended with aerodynamic surface control during some atmospheric phases. The RCS thruster arrangement and control logic is illustrated in Figure 4.3-37.

4.3.2.2 Entry Guidance - Considerable analysis has been performed to develop a guidance system for the hypersonic flight phase. Consideration was given to both fixed L/D (constant angle of attack) and a variable trim capability. General objectives in both system developments were:

a. Small position errors at the reentry terminus.
b. Operation within temperature and load constraints.
c. Reasonable flight computer requirements.

Originally trajectory constraints were considered in the guidance equations with a maximum drag acceleration. However, since it is expected that the uncertainty in normal force coefficient (5%) will be less than the drag uncertainty (15%), the trajectory constraint was changed to a maximum normal



SIMULATION VEHICLE COORDINATE AXES

Figure 4.3–18

WEIGHT = 252,222 LB

CG_X = 67.3% l_b

CG_Y = 0

CG_Z = –13.33 FT FROM X-AXIS

I_{XX} = 2,268 x 10^3 SLUG-FT^2

I_{YY} = 12,724 x 10^3 SLUG-FT^2

I_{ZZ} = 13,265 x 10^3 SLUG-FT^2

I_{XZ} = –76 x 10^3 SLUG-FT^2

MASS PROPERTIES SUMMARY

Figure 4.3–19

	SUBSONIC	TRANSONIC	SUPERSONIC	HYPERSONIC
LONGITUDINAL	CONFIGURATION: 050, REVISION B_1 ADJUSTED FOR REVISION G SOURCE: MCAIR LSWT 0.04 SCALE TEST	CONFIGURATION: 050, REVISION B_1 ADJUSTED FOR REVISION G USING WOODWARD ESTIMATES SOURCE: AMES 6 x 6 WIND TUNNEL TESTS	CONFIGURATION: 050, REVISION B_1 SOURCE: LANGLEY UPWT TEST – SERIES I	CONFIGURATION: 050, REVISION B SOURCE: DATA BOOK (HABP ESTIMATIONS)
LATERAL – DIRECTION	CONFIGURATION: 050, REVISION B SOURCE: AERO DATA BOOK	CONFIGURATION: 050, REVISION B SOURCE: AMES 6 x 6 WIND TUNNEL TESTS (5 MARCH) AERO DATA BOOK, REV I (17 MARCH)	CONFIGURATION: 050, REVISION B_1 SOURCE: LANGLEY UPWT TEST – SERIES I	CONFIGURATION: 050, REVISION B SOURCE: DATA BOOK (HABP ESTIMATIONS)

SIMULATION AERO REPRESENTATION

Figure 4.3–20

$M \leq 4$

$$C_m = C_m\ M, \delta_e, \alpha) + \left\{ C_{m_q} (M, \alpha) * q + C_{m_{\dot{\alpha}}} (M, \alpha) * \dot{\alpha} \right\} * \left\{ \frac{\bar{C}}{2 * V_T} \right\}$$

$$C_N = C_N (M, \delta_e, \alpha) + \left\{ C_{N_q} (M, \alpha) * q + C_{N_{\dot{\alpha}}} (M, \alpha) * \dot{\alpha} \right\} * \left\{ \frac{\bar{C}}{2 * V_T} \right\}$$

$.8 < M \leq 4$

$$C_A = C_A (M, \delta_e, \alpha)$$

$M < .8$

$$C_{(\ )} = C_{(\ )} (M, \alpha)$$

$$C_A = C_{(1)} + C_{(2)} * \delta_e + C_{(3)} * \delta_e^2 + C_{(4)} * \delta_e^3 + C_{(5)} * \delta_e^4 + C_{(6)} * \delta_e^5$$

$M > 4$

$$C_m = C_m (\delta_e, \alpha, H) + C_{m_q} (H, \alpha) * q * \frac{\bar{C}}{2 * V_T}$$

$$C_N = C_N (\delta_e, \alpha, H) + C_{N_q} (H, \alpha) * q * \frac{\bar{C}}{2 * V_T}$$

$$C_A = C_A (\delta_e, \alpha, H)$$

$$C_D = C_A * \mathrm{COS}\ \alpha + C_N * \mathrm{SIN}\ \alpha + \Delta C_{D_{S_B}} (M, \delta_{S_B}) + C_{D_{\delta_G}} * \delta_G$$

$$C_L = C_N * \mathrm{COS}\ \alpha - C_A * \mathrm{SIN}\ \alpha$$

SIMULATION AERODYNAMIC ALGORITHMS

Figure 4.3–21

GROUND EFFECT: $R_{GE} = \dfrac{2 * H}{b_{SPAN}}$

IF $R_{GE} \leq 2$ THEN

$$C_D = C_D + \frac{\Delta C_{D_{GE}}}{C_{D_\infty}} (R_{GE}) * C_{D_\infty}$$

$$C_L = C_L + \frac{\Delta C_{L_{GE}}}{C_{L_\infty}} (R_{GE}) * C_{L_\infty}$$

$$C_m = C_m + \frac{\Delta C_{m_{GE}}}{C_{L_\infty}} (R_{GE}) * C_{L_\infty}$$

$$C_m = C_m - (C_N * (X_{CG} - X_{CGREF}) - C_A * (Z_{CG} - Z_{CGREF})) / \bar{c}$$

$M > 4$

$$C_y = C_{y_\beta} (H, \alpha) * \beta + \left\{ C_{y_r} (H, \alpha) * r + C_{y_p} (H, \alpha) * p \right\} * \frac{b}{2 * V_T}$$

$$C_e = C_{l_\beta} (H, \alpha) * \beta + \left\{ C_{\ell_r} (H, \alpha) * r + C_{l_p} (H, \alpha) * p \right\} * \frac{b}{2 * V_T}$$

$$C_n = C_{n_\beta} (H, \alpha) * \beta + \left\{ C_{n_r} (H, \alpha) * r + C_{n_p} (H, \alpha) * p \right\} * \frac{b}{2 * V_T}$$

$M \leq 2$

$$C_y = C_{y_\beta} (M, \alpha) * \beta + \left\{ C_{y_r} (M, \alpha) * r + C_{y_p} (M, \alpha) * p \right\} * \frac{b}{2 * V_T} + C_{y_{\delta_R}} (M) * \delta_R + C_{y_{\delta_a}} (M, \alpha) * \delta_a$$

$$C_l = C_{l_\beta} (M, \alpha) * \beta + \left\{ C_{l_r} (M, C_L) * r + C_{l_p} (M, C_L) * p \right\} * \frac{b}{2 * V_T} + C_{l_{\delta_R}} (M) * \delta_R + C_{l_{\delta_a}} (M, \alpha) * \delta_a$$

$$C_n = C_{n_\beta} (M, \alpha) * \beta + \left\{ C_{n_r} (M, C_L) * r + * \ C_{n_r} (M, C_L) * r + C_{n_p} (M, C_L) * p \right\} * \frac{b}{2 * V_T} + C_{n_{\delta_R}} (M) * \delta_R + C_{n_{\delta_a}} (M, \alpha) * \delta_a$$

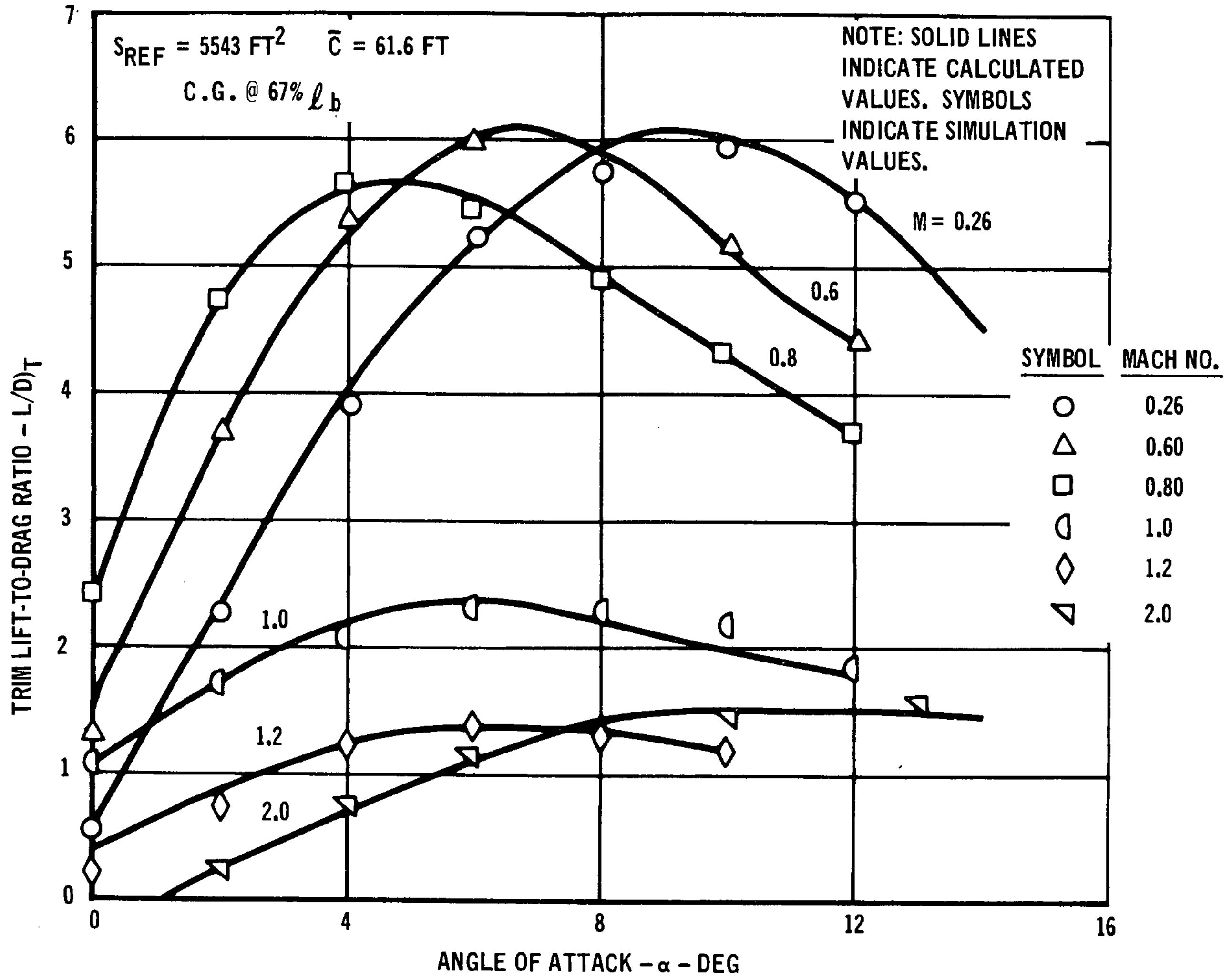
$2. < M \leq 4$

$C_{(\ )_r}$ DERIVATIVES ARE FUNCTIONS OF α AND MACH NUMBER

$C_{(\ )_r}$ AND $C_{(\ )_p}$ DERIVATIVES ARE LINEAR INTERPOLATIONS BETWEEN THE VALUE AT M= 4.
AND THE VALUE AT M = 2.

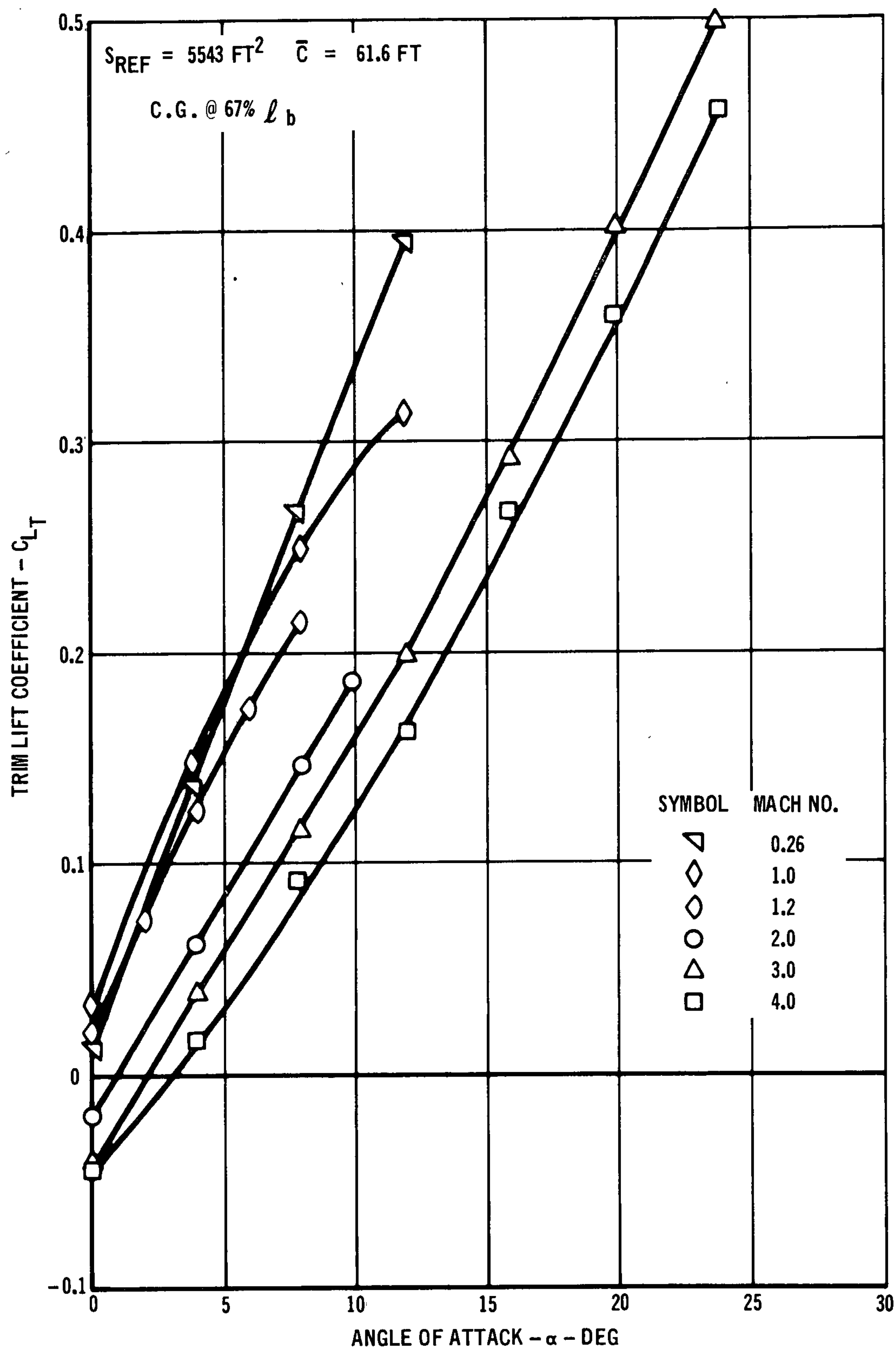
SIMULATION AERODYNAMIC ALGORITHMS (Continued)

Figure 4.3–21



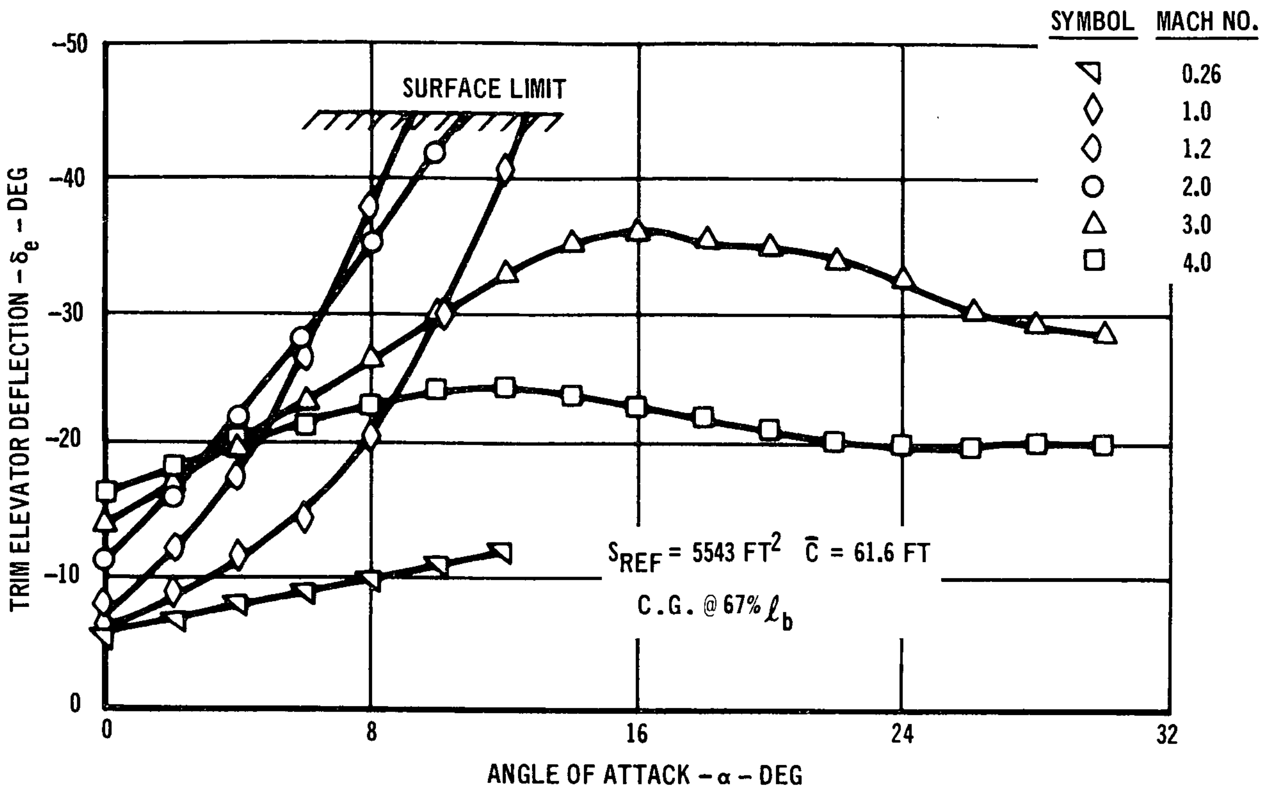
TRIM LIFT TO DRAG CHARACTERISTICS

Figure 4.3–22



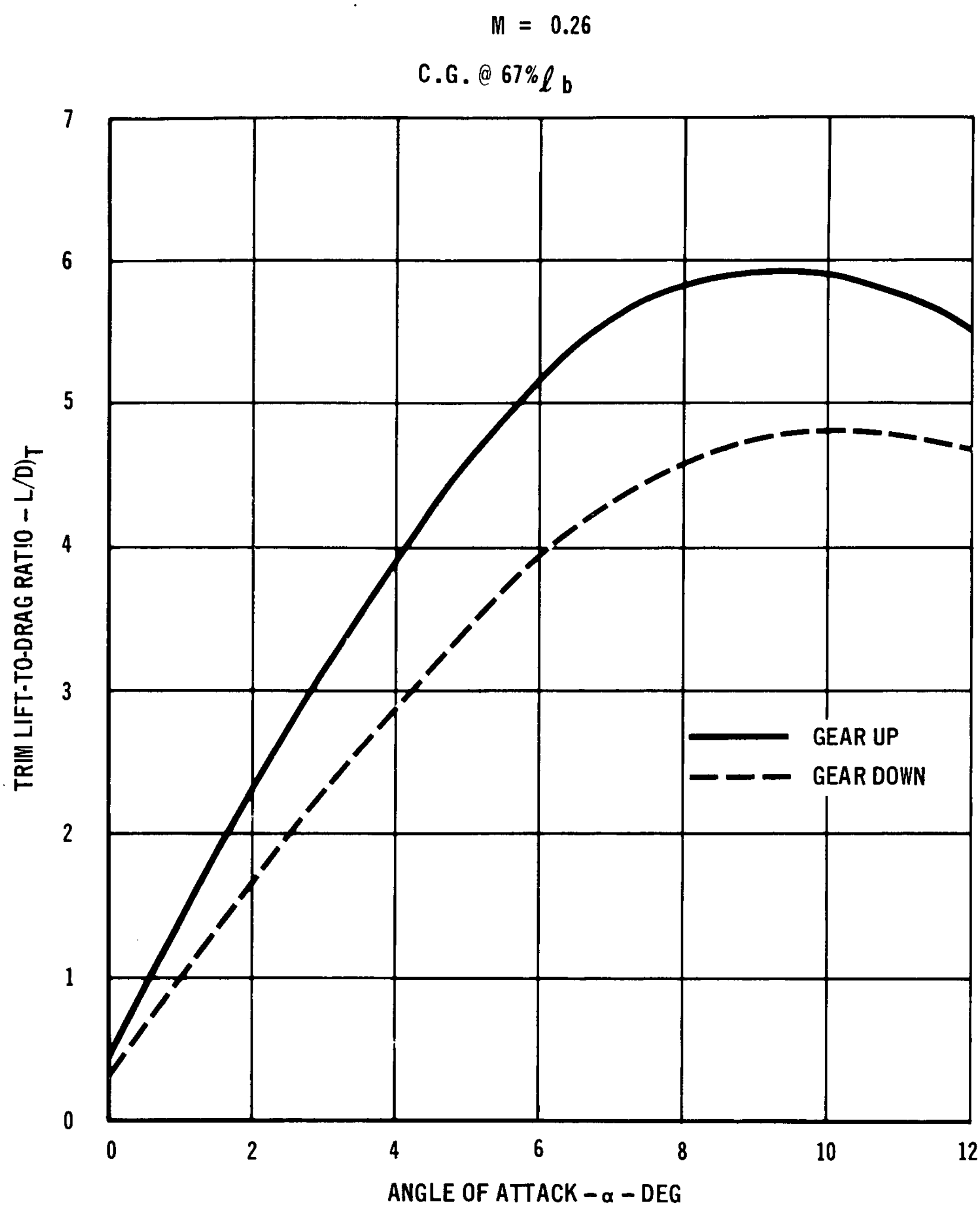
TRIM LIFT CHARACTERISTICS

Figure 4.3–23



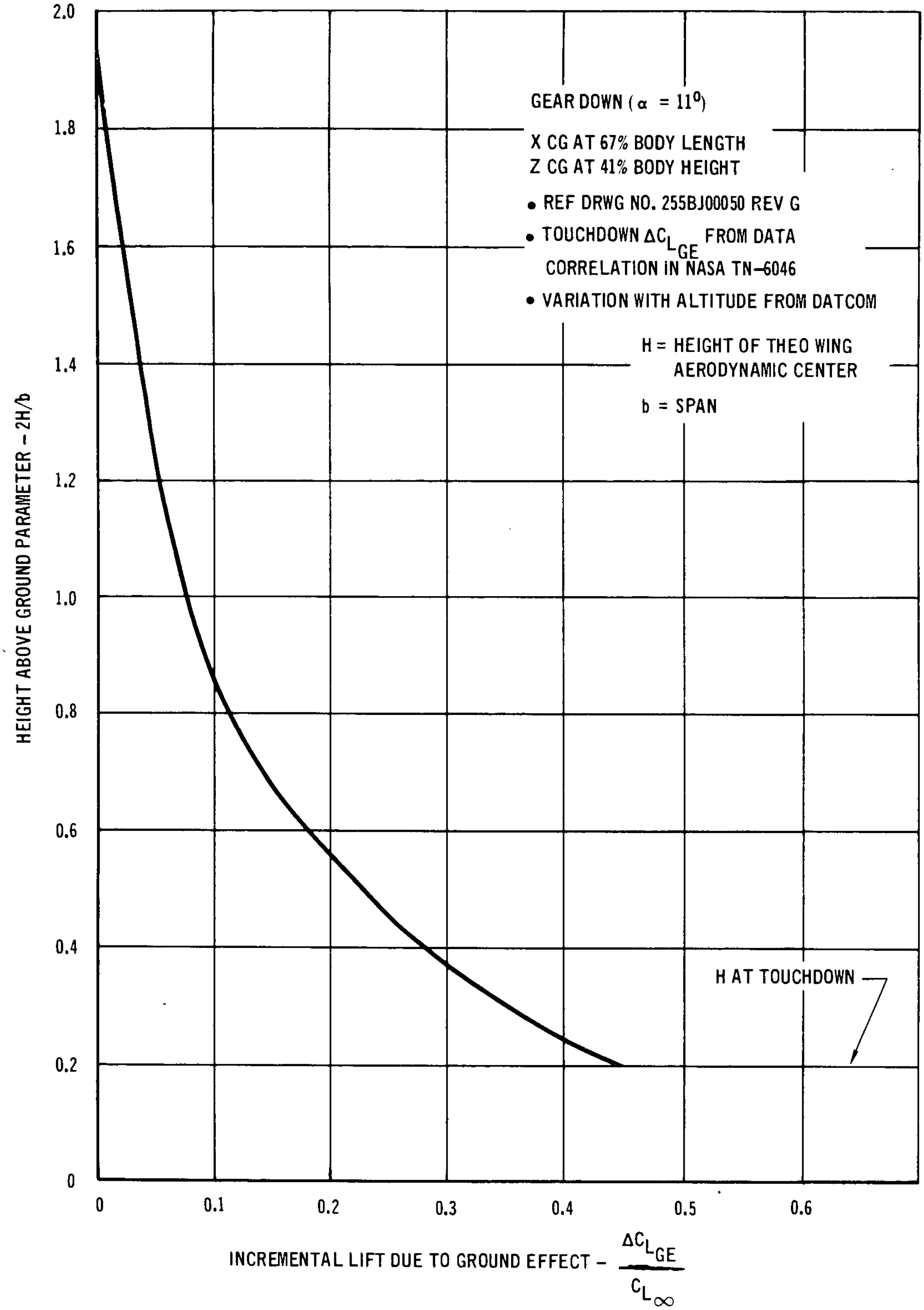
TRIM ELEVATOR CHARACTERISTICS

Figure 4.3–24



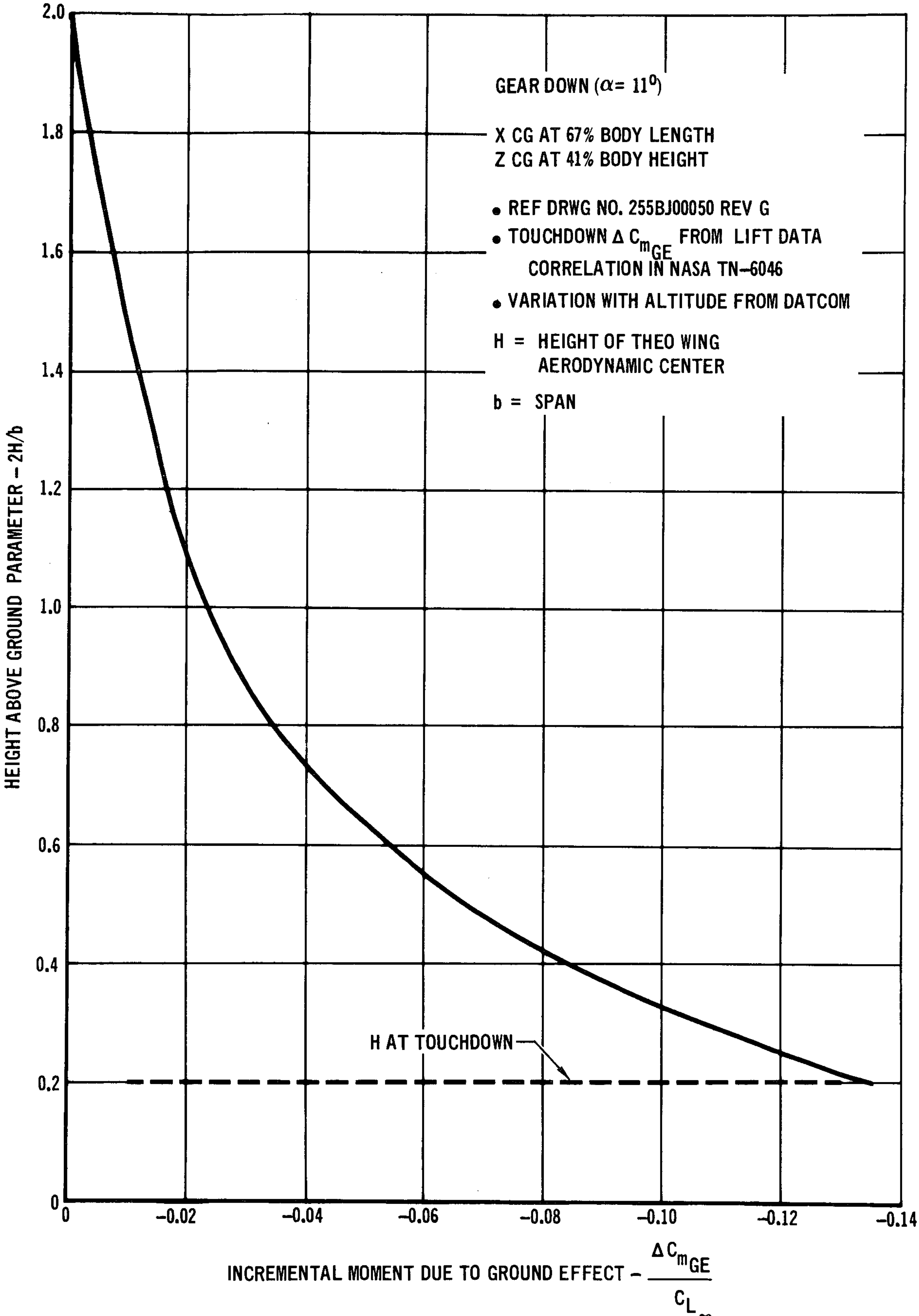
LANDING GEAR EFFECTS ON TRIM L/D

Figure 4.3–25



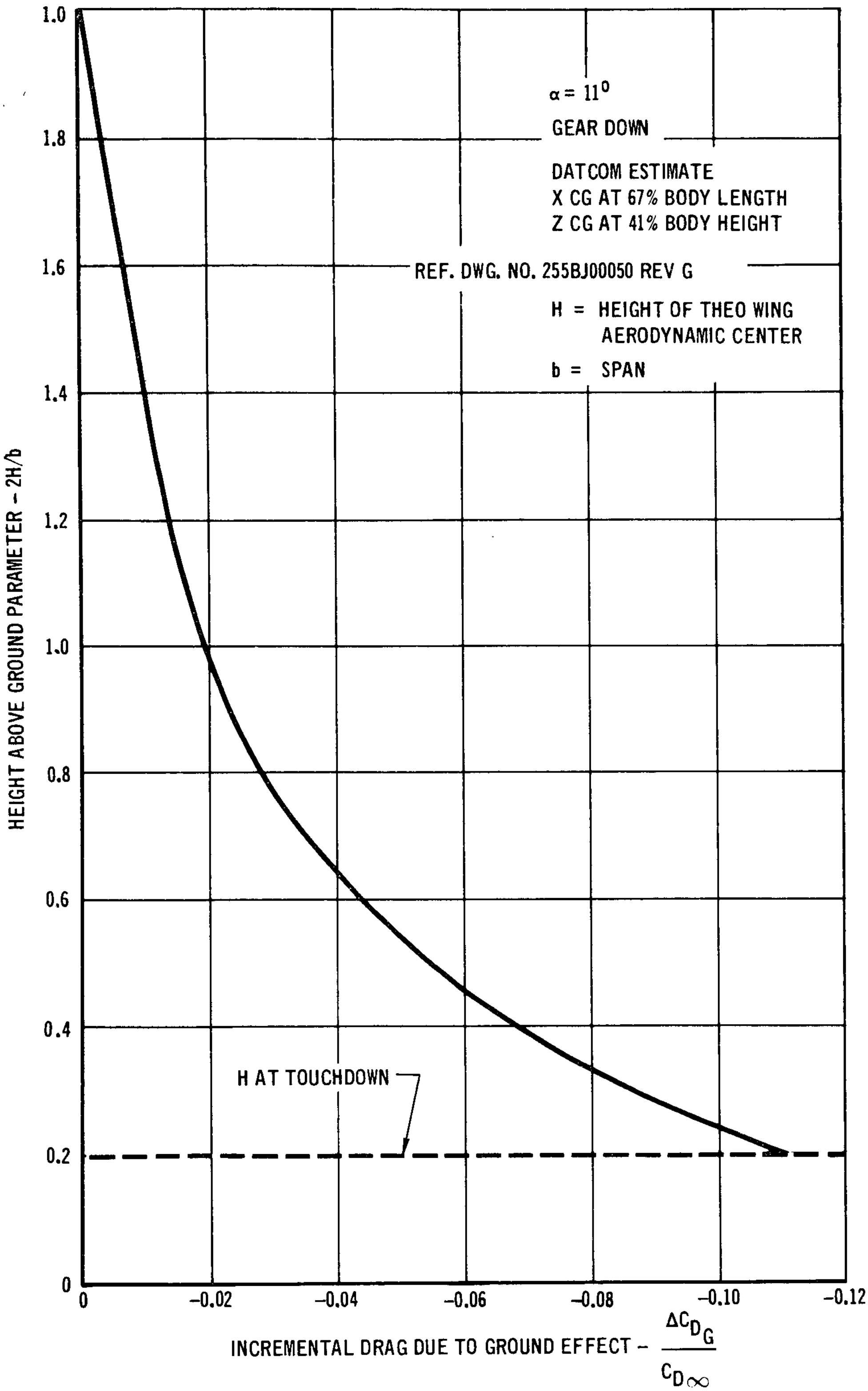
INCREMENTAL LIFT DUE TO GROUND EFFECTS

Figure 4.3–26



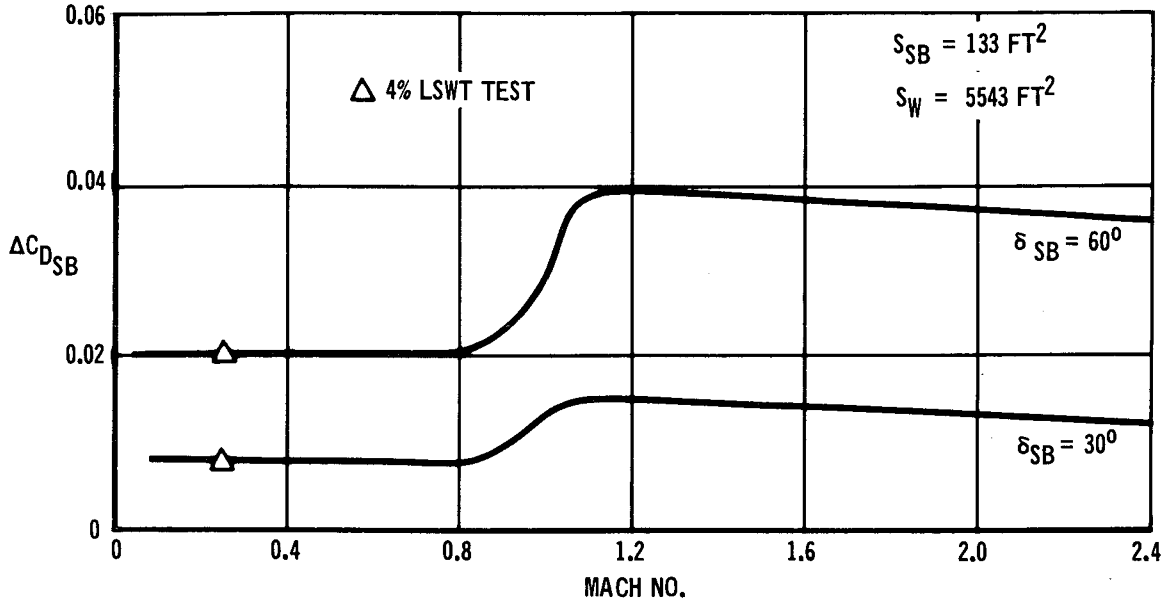
INCREMENTAL MOMENT DUE TO GROUND EFFECTS

Figure 4.3–27



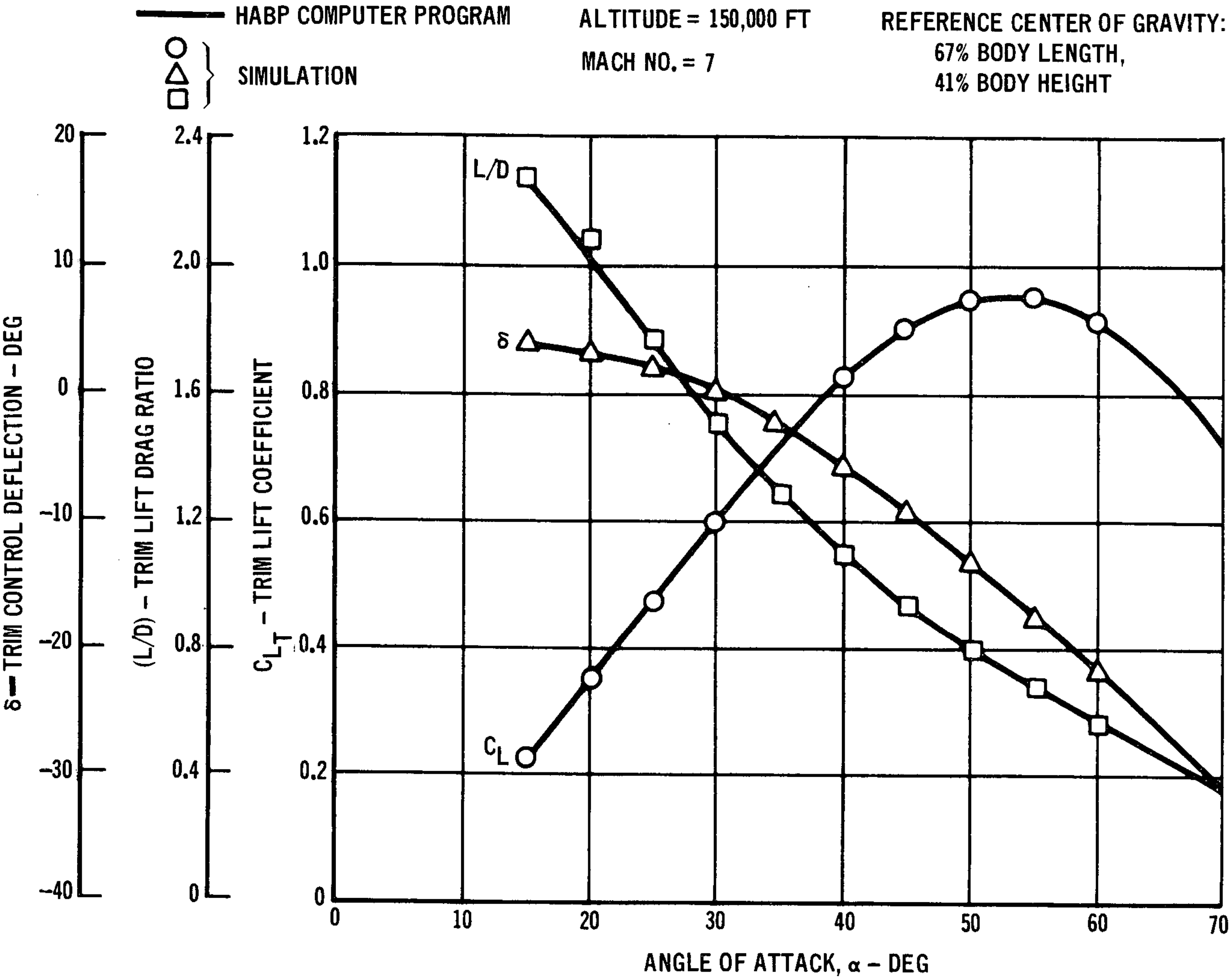
INCREMENTAL DRAG DUE TO GROUND EFFECTS

Figure 4.3–28



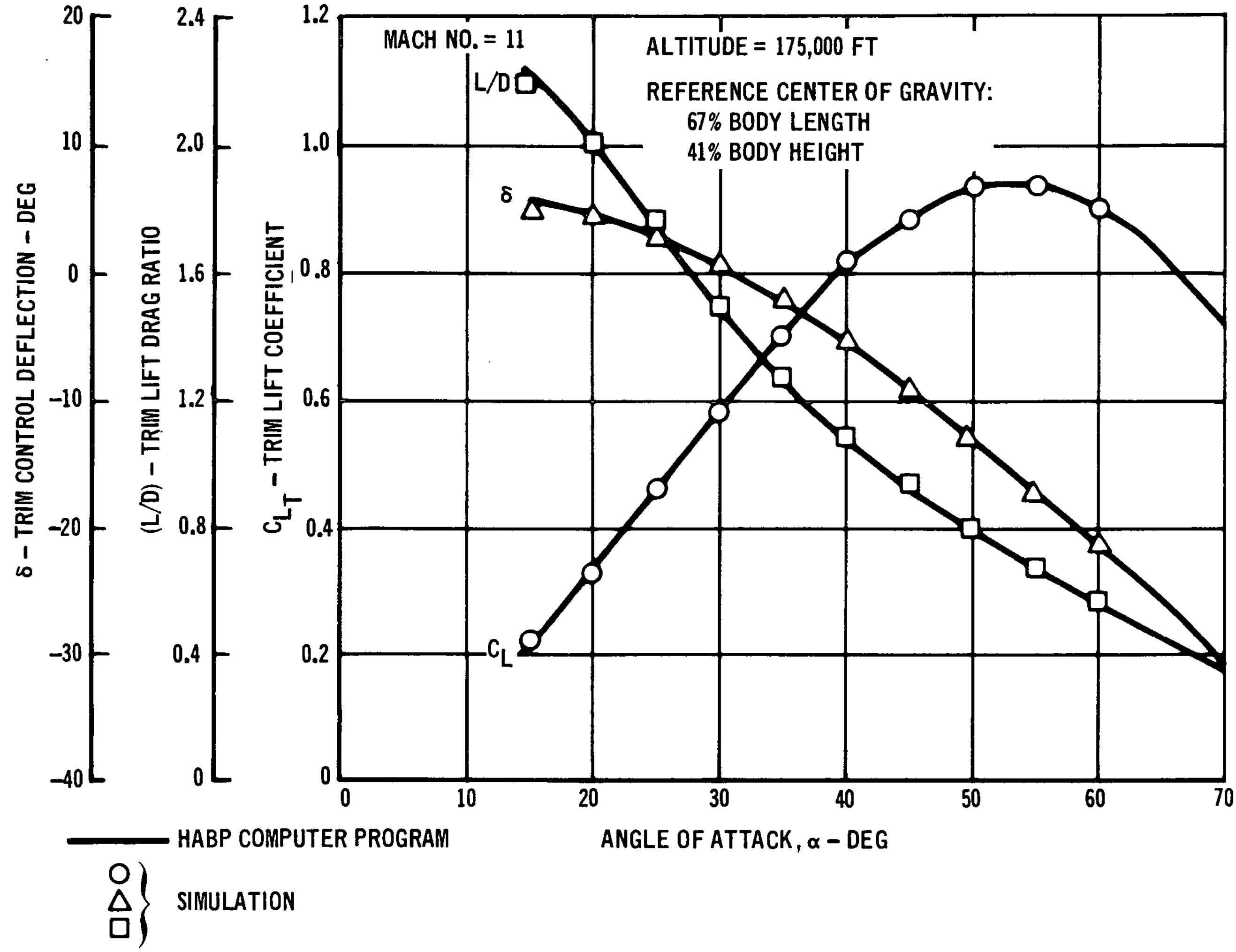
FUSELAGE SPEED BRAKE DRAG

Figure 4.3–29



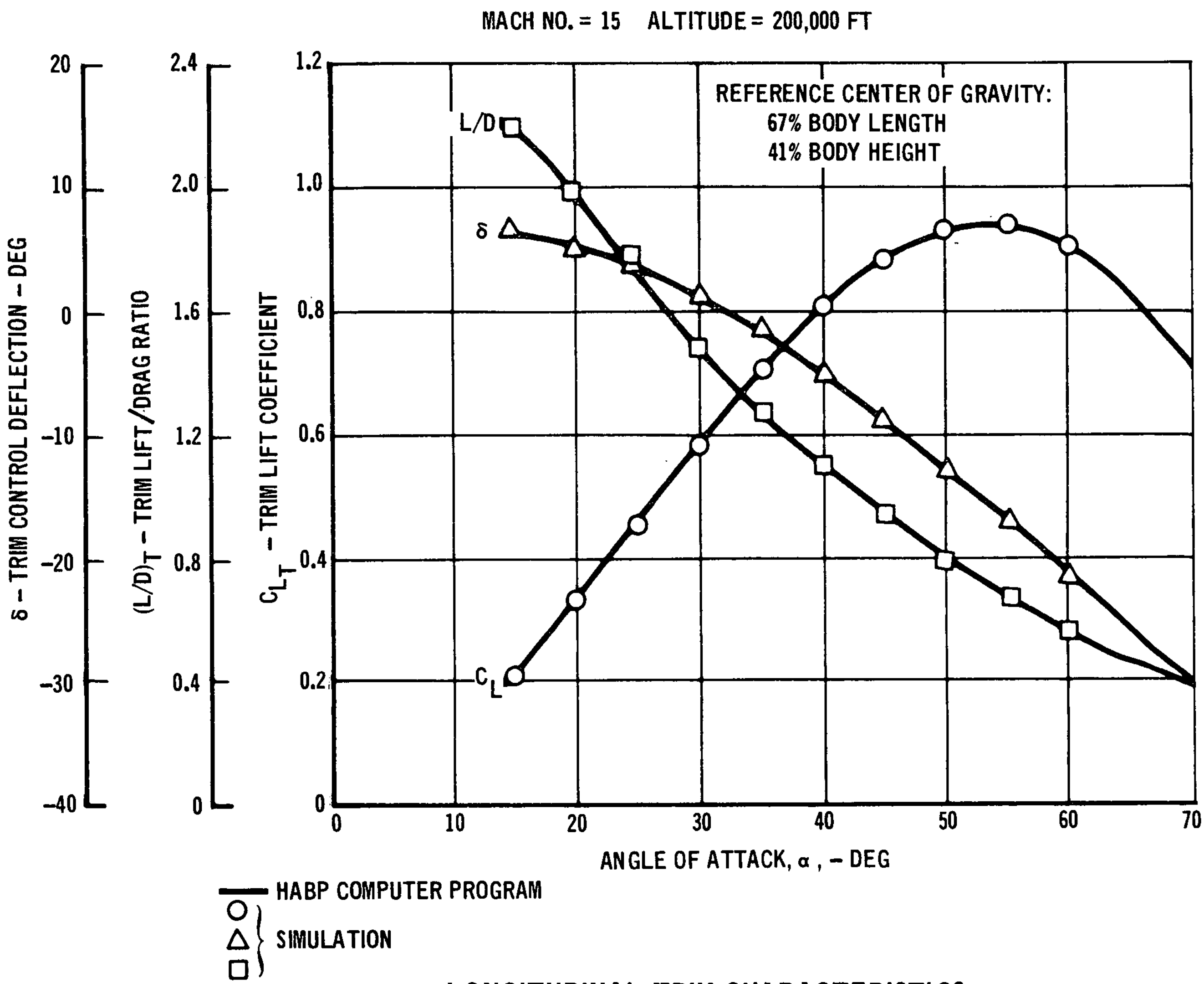
LONGITUDINAL TRIM CHARACTERISTICS

Figure 4.3–30



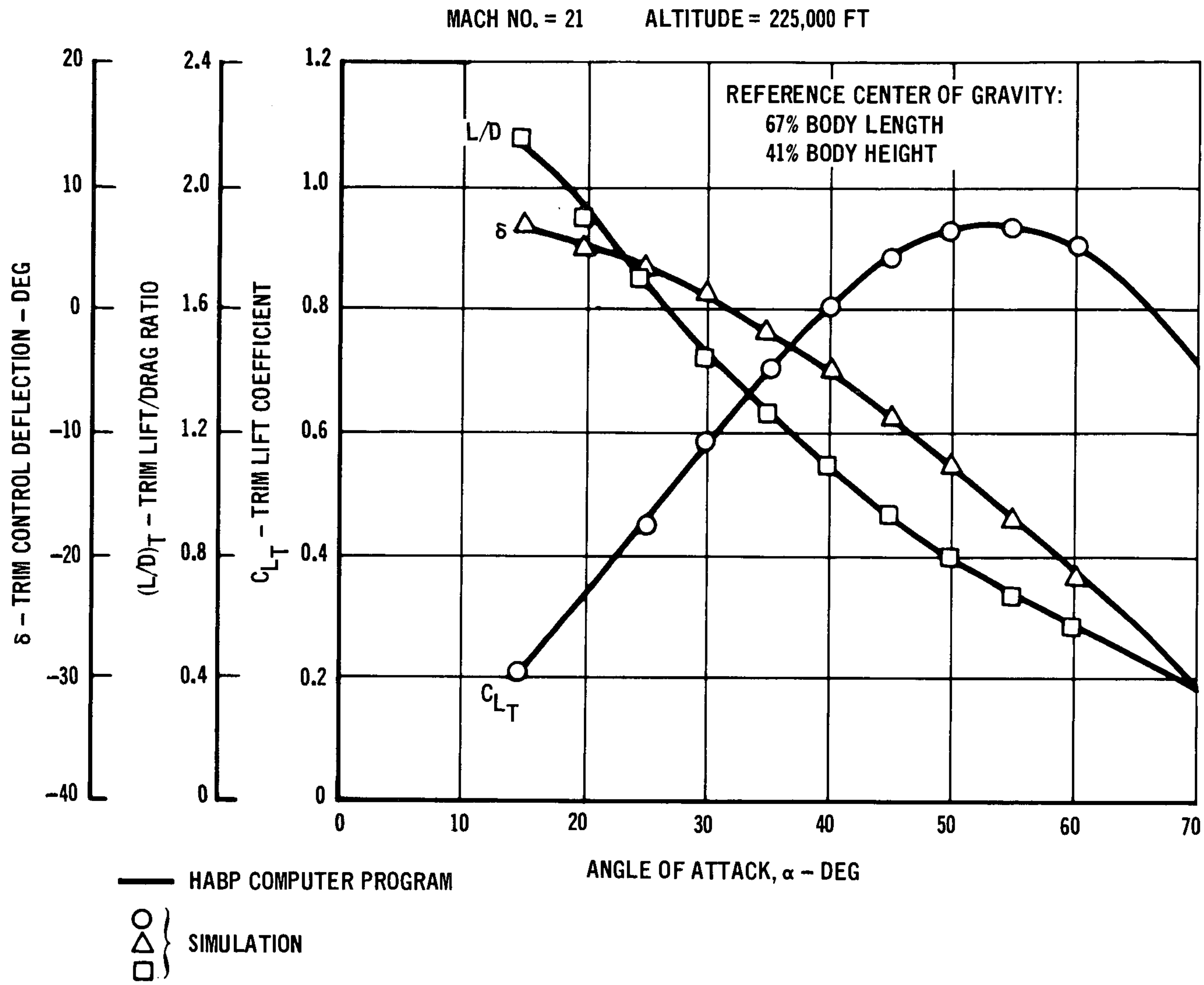
LONGITUDINAL TRIM CHARACTERISTICS

Figure 4.3–31



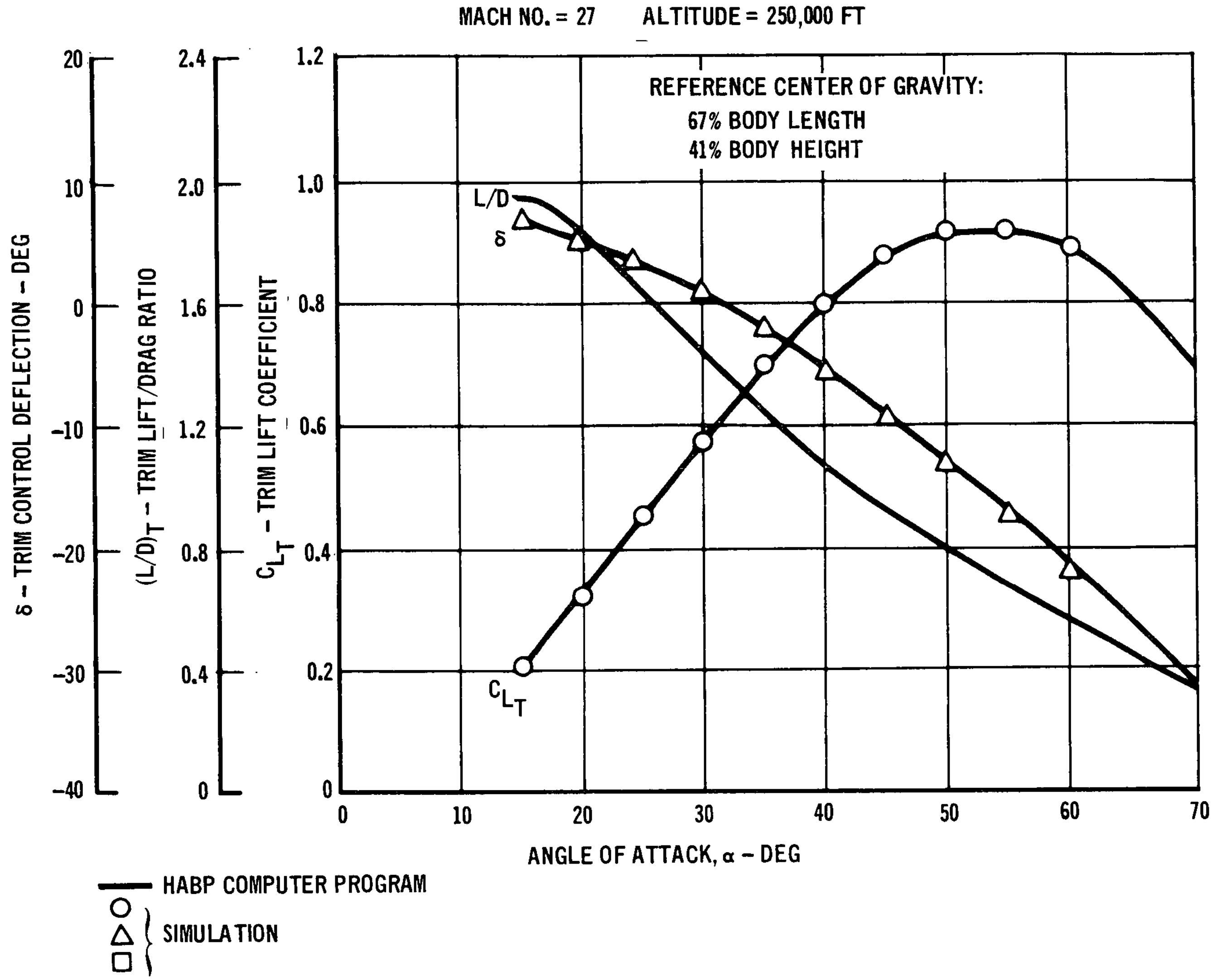
LONGITUDINAL TRIM CHARACTERISTICS

Figure 4.3–32



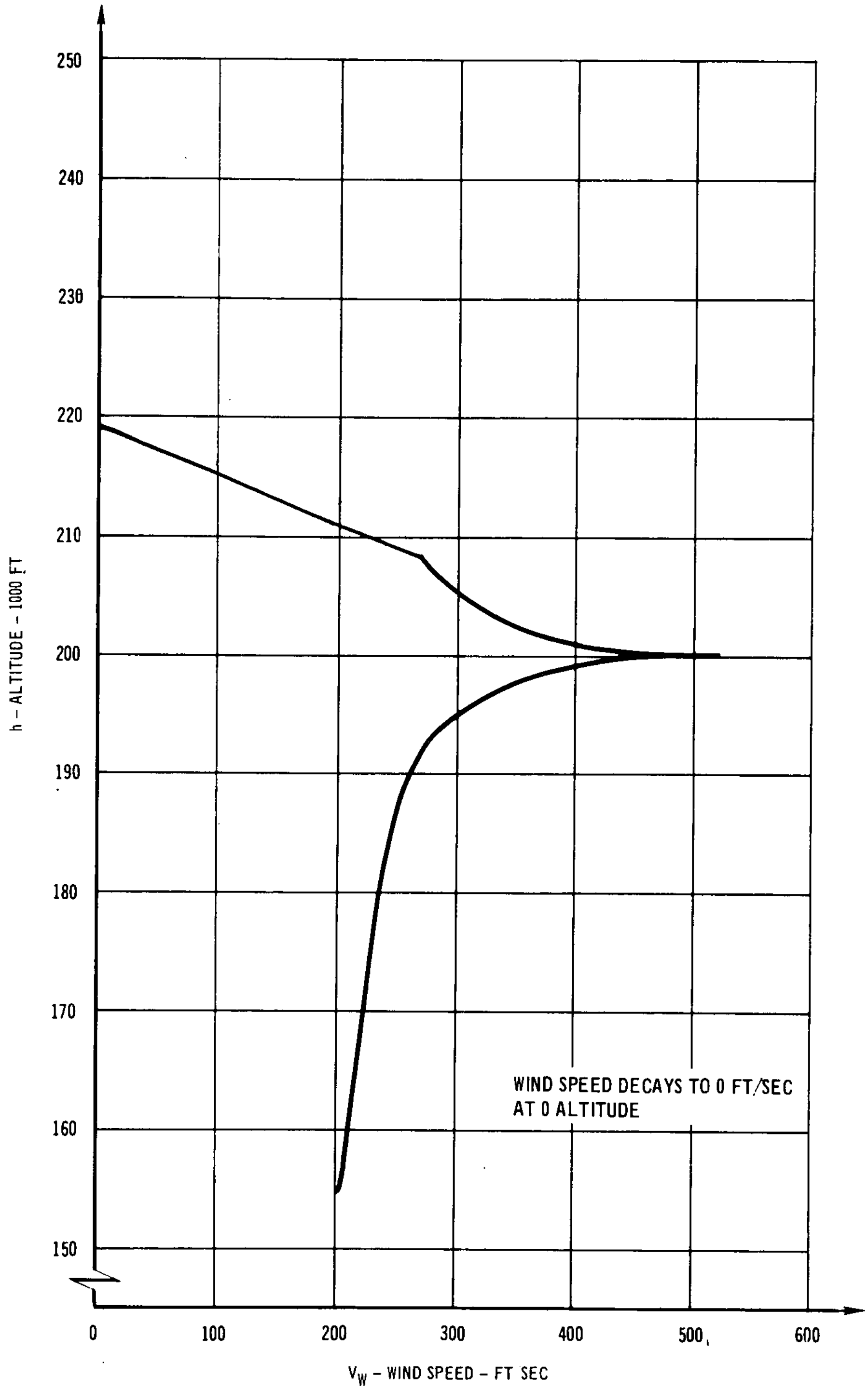
LONGITUDINAL TRIM CHARACTERISTICS

Figure 4.3–33



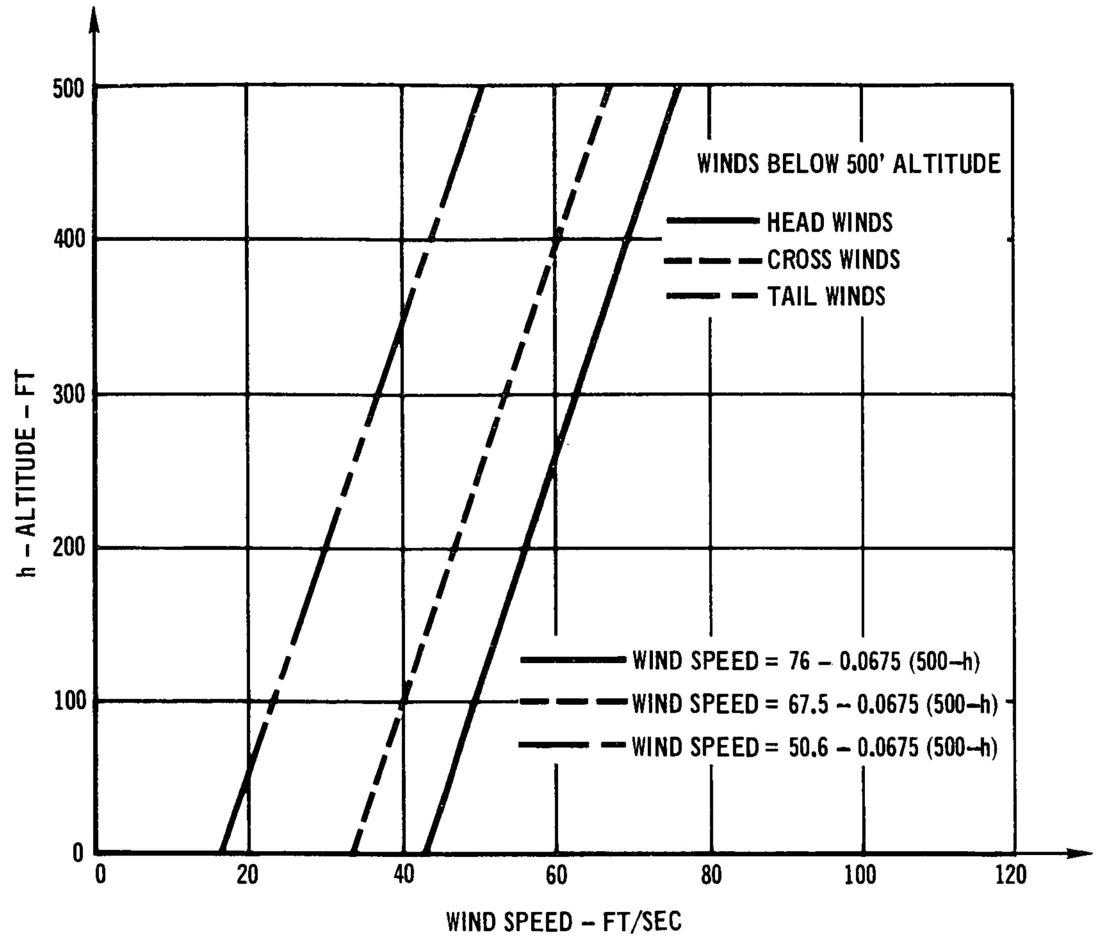
LONGITUDINAL TRIM CHARACTERISTICS

Figure 4.3–34



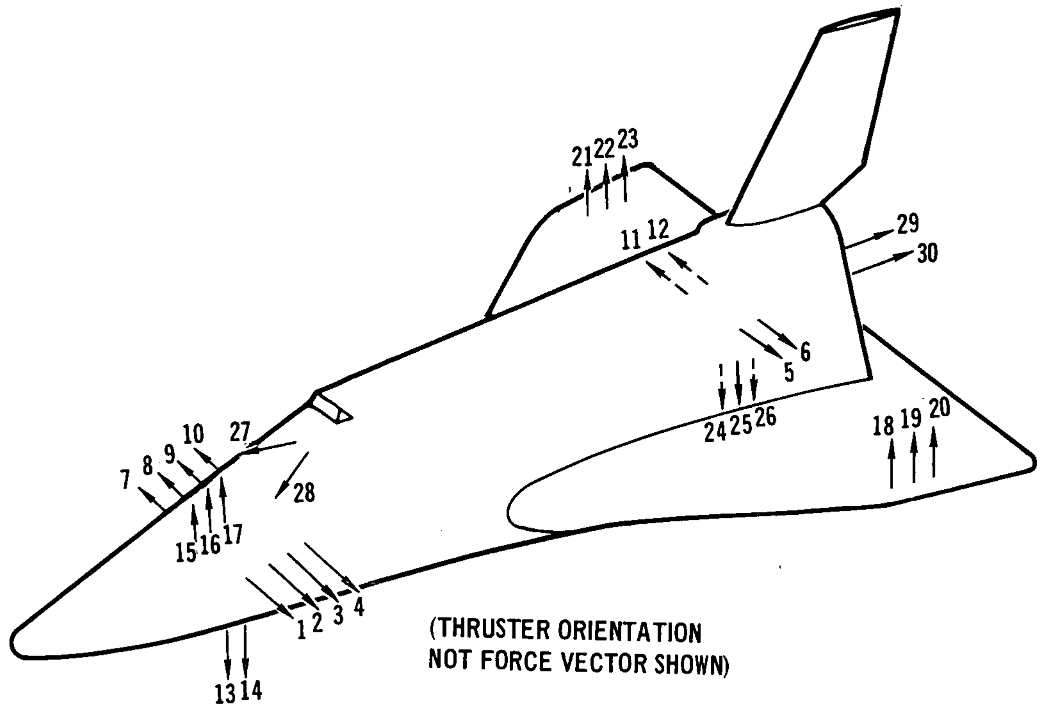
WIND PROFILE FOR ENTRY

Figure 4.3–35



WIND PROFILE FOR LANDING

Figure 4.3–36



(THRUSTER ORIENTATION
NOT FORCE VECTOR SHOWN)

1600 POUND THRUST MAGNITUDE

THRUSTER	LOCATION (FT)		
	X_{REF}	Y_{REF}	Z_{REF}
1, 2, 3, 4	25	−6.0	23.5
5, 6	154	−7.5	28.0
7, 8, 9, 10	25	6.0	23.5
11, 12	154	7.5	28.0
13,14	16	2.5	16.0
15,16,17	16	0.0	23.0
18, 19, 20	149	−44.0	20.0
21, 22, 23	149	44.0	20.0
24, 25, 26	149	0.0	16.0
27	26	7.0	25.5
28	26	−7.0	25.5
29	160	2.5	25.5
30	160	−2.5	25.5

CONTROL FUNCTION	THRUSTER	
	ON ORBIT	ENTRY
PITCH UP	13, 14, 18, 21	18, 21
PITCH DOWN	15, 24	15
ROLL RIGHT	21, 24	21, 22
ROLL LEFT	18, 24	18, 19
YAW RIGHT	1, 11	1, 2, 3
YAW LEFT	5, 7	7, 8, 9
TRANSLATE		
FORWARD	29, 30	
AFT	27, 28	
UP	13, 24, 25	
DOWN	15, 18, 21	
RIGHT	1, 5, 6	
LEFT	7, 11, 12	

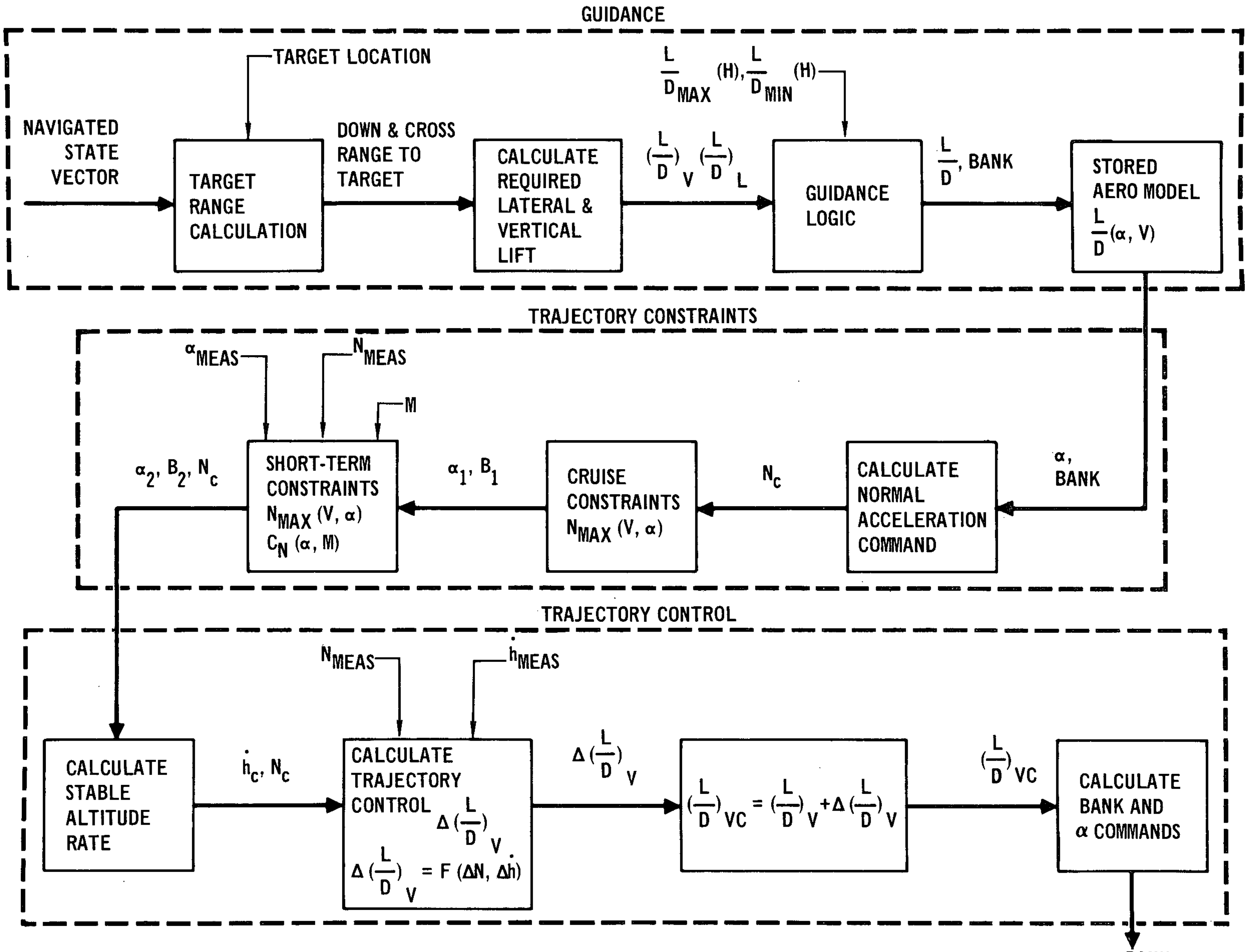
RCS THRUSTER ARRANGEMENT AND CONTROL DEFINITION

Figure 4.3–37

acceleration. Trajectory damping terms were also included in the guidance equations to prohibit normal acceleration from exceeding a maximum value. Closed form equations are used to estimate lift requirements, and hence onboard computer requirements are modest with no requirement for first time integration of the equations of motion. It is estimated that 1900 - thirty-two bit locations are required for the complete system.

A functional diagram of the guidance math flow is shown in Figure 4.3-38 for the simulated variable trim guidance system. Detailed math flow of the guidance equations and logic along with a derivation of the equations are presented in References B and C. The sequence of calculations is: (1) determine the longitudinal and lateral ranges to the target, (2) calculate the required lateral and vertical lift to reach the target, (3) determine the corresponding angle of attack and bank angle commands, (4) compare the lift requirements with the stored constraint model and (if necessary) change the commands to avoid violating the constraints, and finally, (5) calculate changes in lift commands to control the actual trajectory to the trajectory commanded by guidance.

Target Range Calculation - The objective of these calculations is to describe the downrange, crossrange, and scalar range to the target. Since Coriolis acceleration causes the zero-bank ground track of a reentry trajectory over the earth to differ significantly from a great circle path, the lateral range error calculated from spherical trigonometry using the heading angle of the relative velocity vector is inaccurate. The technique to estimate down range and cross range distances to the target is by using spherical trigonometry. The cross range is modified in the guidance system by accounting for the Coriolis effects. These effects are estimated by a second order numerical integration with



REENTRY GUIDANCE FUNCTIONAL DIAGRAM

Figure 4.3-38

velocity as the independent variable. Scalar range to the target is estimated as the range along a minor circle connecting the vehicle and target positions and tangent to the initial velocity vector. This provides a better approximation to the actual range along the controlled path than using the great circle range.

Lift Requirement - Vertical and lateral lift to drag ratios required to reach the target at a specified velocity in an equilibrium glide are calculated using closed form equations. Vertical plane L/D is derived from the range rate equation ($\dot{R}=V$), based on assuming near-horizontal flight, where the velocity dynamics can be approximated by differentiating vehicle energy and equating the result to energy dissipation resulting from drag. Required lateral $(L/D)_L$ is calculated by expanding the one-step Simpson rule integration equation for lateral range as a second order series in $(L/D)_L$, substituting target lateral range, and solving for $(L/D)_L$.

Guidance Logic - Functions of the guidance logic are to assign overcontrol gains to the required L/D values and then calculate the commanded angle of attack and bank angle values. Overcontrol is used to drive the required guidance values to normal levels near the end of reentry flight (nominal values are zero bank and a "middle" value of angle of attack). A stored table describing L/D behavior as a function of angle of attack and altitude (or velocity) is used to convert the commanded L/D to the corresponding angle of attack command. This conversion has three logical exits.

MODE (1) $(L/D)_C > (L/D)_{MAX}$

MODE (2) $(L/D)_{MIN} \leq \frac{L}{D}_C \leq \frac{L}{D}_{MAX}$

MODE (3) $(L/D)_C < \frac{L}{D}_{MIN}$

In MODE (1), commanded bank angle is calculated to either reduce the lateral overcontrol gain and satisfy the vertical (L/D) or provide vertical and lateral (L/D) in the correct ratio when the lateral overcontrol gain is reduced to a minimum value. This logic permits using a large lateral overcontrol without sacrificing vertical control when the target is on the extreme boundary of the achieveable ground area. In MODE (3) the vehicle is flown along a zig-zag path using a lateral deadband. In MODE (2) the commanded value is flown.

Trajectory Constraints - Logic is included to avoid the following:

- o Top of vehicle overheating.
- o Bottom of vehicle overheating.
- o Normal acceleration limit for passenger comfort.

The vehicle top is protected from overheating by constraining the commanded angle of attack to be greater than 25 degrees. The bottom of the vehicle is protected by adjusting the guidance commands (α_c and Bc) such that the normal acceleration doesn't exceed the constrained value defined by the temperature limits for equilibrium glide and short term conditions. The maximum normal acceleration is limited to 2 g's. The normal acceleration that results in equilibrium flight at the L/D values commanded by the guidance are calculated and compared to the maximum allowable value based on the present velocity and commanded angle of attack. If the guidance commands violate the constraint, commanded angle of attack and/or bank angle are changed so the equilibrium trajectory borders the constraint. Generally, the change in commands is based on satisfying the constraint with minimum variations from the guidance L/D values; that is, both angle of attack and bank angle are changed from the values command by guidance.

Initially, a new angle of attack (α_1) and bank angle (B_1) are calculated which minimizes a penalty function (P) based on downrange and crossrange obtainable with the new set of angles as compared to the guidance command α and B. The equations will obtain an α_1 which minimized P (α, B) subject to Cos B <1 and a B_1 which will control the trajectory to the constraint. The ranges are based on equilibrium glide and hence the α_1 and B_1 are designated as constraints for cruise.

However, the new command angle of attack (α_1) must be evaluated at the present flight conditions to see if the normal acceleration obtained when going to α_1 exceeds the constraint. If it does, a new angle of attack (α_2) is calculated which will allow the vehicle to border the constraint and B_2 is calculated to produce cruise at α_1, B_1 flight conditions. The α_2 and B_2 are short term constraints which would change continually as the vehicle altitude trajectory changes due to the maneuvers, eventually becoming equal to the α_1 and B_1 cruise constraints.

<u>Trajectory Control and Damping</u> - The normal acceleration and altitude rate required for equilibrium flight at the command L/D values are calculated after considering trajectory constraints. Measured values of normal acceleration (adjusted for angle of attack differences) and altitude rate are then combined with the equilibrium values in a linear feedback equation to calculate the variation in vertical (L/D) required to drive the trajectory toward equilibrium in the vertical plane. When the velocity is greater than 12500 fps, changes in bank angle are used for trajectory control. Below 12500 fps (and when the guidance mode is not mode (3)) angle of attack is modulated for trajectory control. When angle of attack modulation is used, the feedback law is changed slightly. During this period, the integral of normal acceleration error is fed-back and a "washout" operator that attenuates high frequency signal content is applied

to the altitude rate error. This control method is the result of a brief study of trajectory control at low speeds and was found better than the linear feedback law. However, the feedback law should not be considered a "final form" since the emphasis of the analysis has been on trajectory control at higher velocities and guidance rather than trajectory control below a velocity of 12500 FPS. A switch velocity of 12500 FPS was chosen as the break point between bank angle and angle of attack damping because mode (2) guidance is generally in use by the time a speed of 12500 FPS is achieved. That is, overcontrol will usually drive the control variable out of saturation and near nominal levels during the period between entry and the switch velocity.

4.3.2.3 Terminal Guidance - The terminal guidance techniques employed in the simulation were developed specifically for the unpowered terminal approach of the Orbiter as documented in References D, E, and F. This section describes the guidance concepts and logic as discussed in the references.

The Terminal Area Guidance (TAG) system provides steering commands and status information to the pilot during the transition, approach, and landing. The system is capable of compensating for large dispersions in initial range, cross-range, and altitude, independent of initial vehicle heading. The target point for initiation of the TAG flight phase is located approximately 100 NM from the start of final approach at a nominal altitude of 125,000 feet at Mach 4, which are the nominal conditions for initiating transition and cruise to the runway. The geometry of the target point relative to the runway is presented in Figure 4.3-39.

Guidance Technique - The TAG system is divided into the following 4 phases which are illustrated in Figure 4.3-40.

TERMINAL AREA GEOMETRY

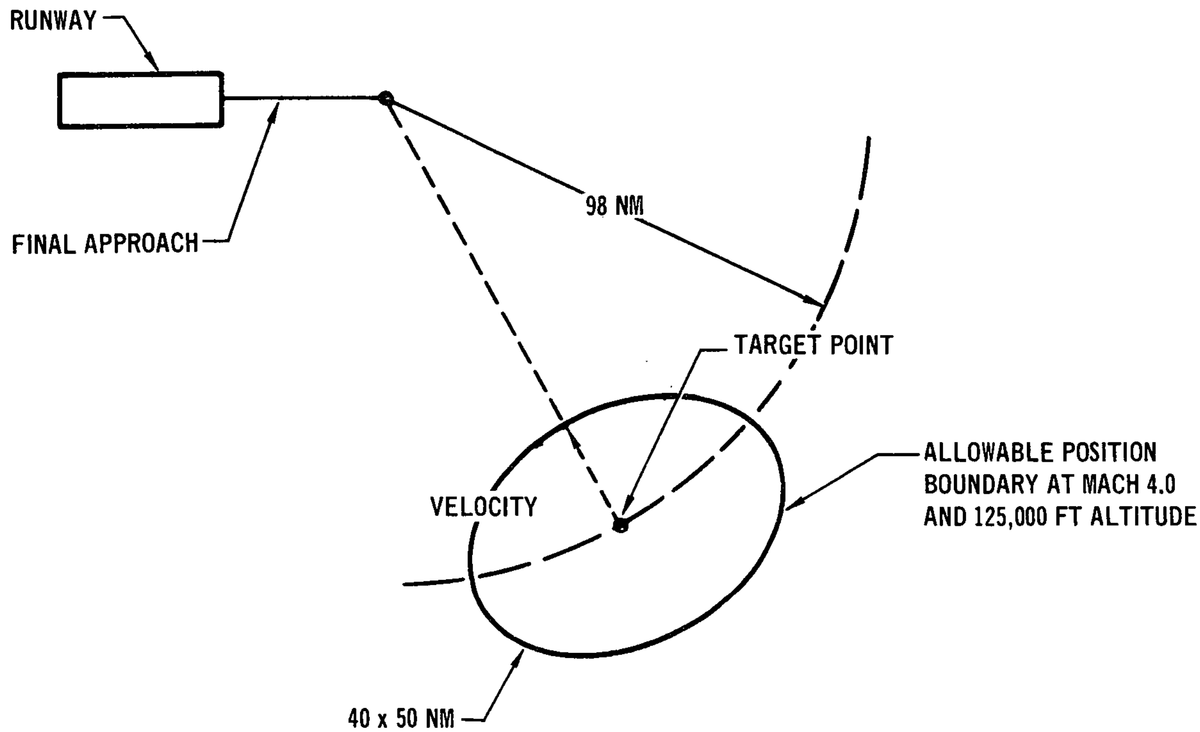
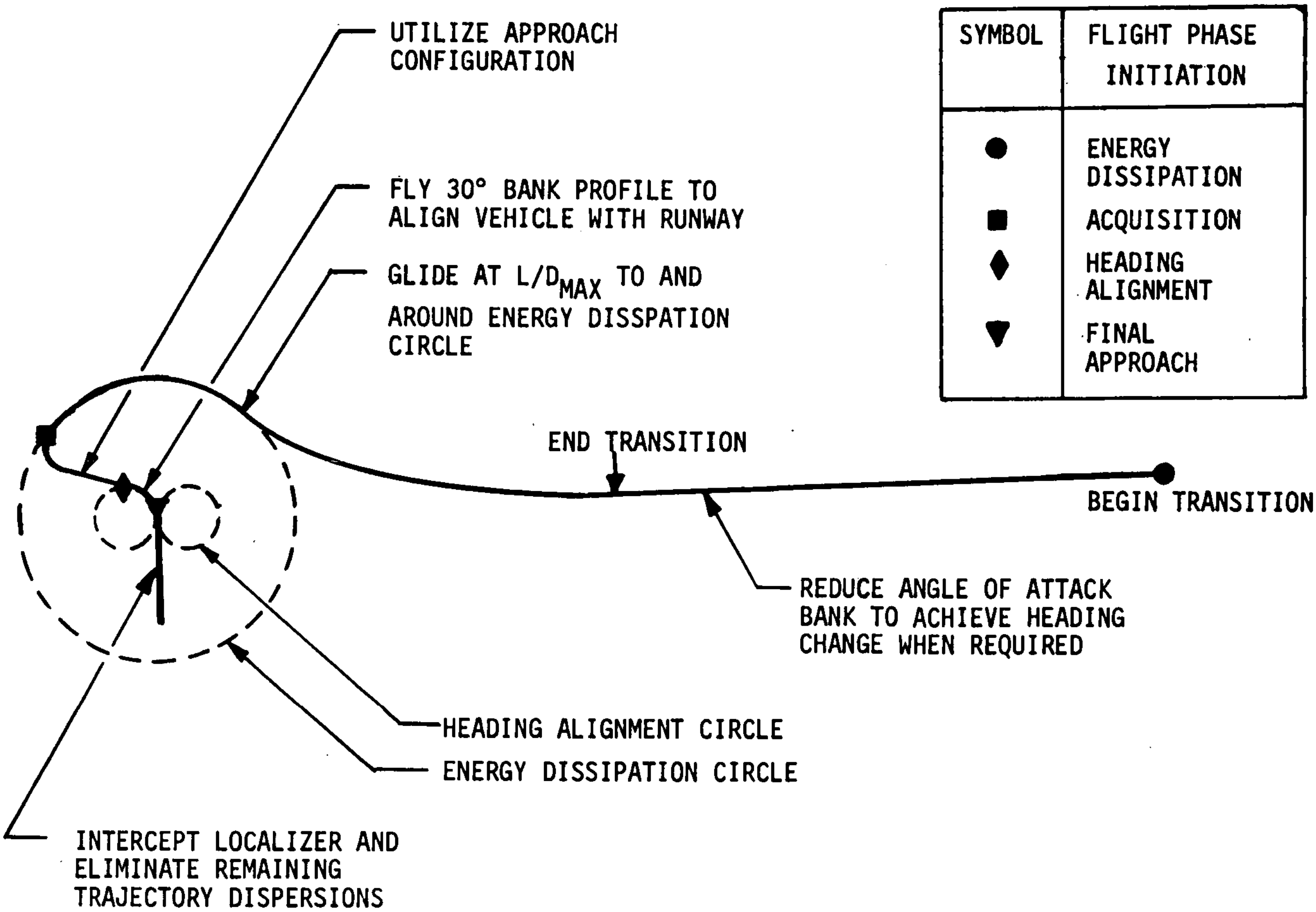


Figure 4.3–39



SYMBOL	FLIGHT PHASE INITIATION
●	ENERGY DISSIPATION
■	ACQUISITION
♦	HEADING ALIGNMENT
▼	FINAL APPROACH

TERMINAL AREA GUIDANCE SYSTEM FLIGHT PHASES

Figure 4.3–40

(1) Energy Dissipation (ED)

(2) Acquisition of the Heading Alignment Circle (AC)

(3) Heading Alignment (HA)

(4) Final Approach (FA)

The guidance logic switches from ED to AC and from AC to HA on energy. The energy at which this switching occurs is dependent on the nominal trajectory selected for the system baseline. The logic may switch from HA to FA on either vehicle heading or on a fixed energy level, whichever occurs first. All four phases may not necessarily occur, for example, if the vehicle is initially at extreme range, the ED phase is not necessary and the AC phase will be initiated immediately. Some off-nominal conditions may cause the vehicle to arrive in the vicinity of the nominal HA circles with excess energy. Under these circumstances the AC phase will perform the HA phase and the HA phase will not be utilized.

During the ED phase the lateral guidance directs the vehicle toward and around the ED circle while the vehicle is flown at the nominal angle of attack. The radius of the ED circle is set at 14.5 NM to allow the vehicle to track the circle at supersonic speeds with reasonable bank angles. The distance between the vehicle and the HA circle ($\Delta\psi_{AC}$) are continuously computed and used to estimate the ground track range which the vehicle must fly. The estimated range to reach the HA circle is summed with the range required during the HA and FA phases. When the total is equal to or exceeds the vehicle's nominal range capability the ED phase is terminated, and the AC phase is initiated. The vehicle is then directed toward the HA circle.

During the AC phase, bank command is proportional to $\Delta\psi_{AC}$. The estimated ground track range required to complete the flight is computed, compared with the vehicle's nominal range capability and used to modulate angle of attack and speed brake position around their nominal values. The AC phase is terminated when the vehicle's energy equals the estimated energy necessary to complete the HA and FA phases. If the energy is too high upon reaching the HA circle, the system will follow the nominal HA path very closely even though the energy is too high for the AC phase to be terminated. The AC phase itself can perform the HA phase function of turning the vehicle toward the runway since it computes the commanded heading, during AC, to be the heading of a vector from the vehicle tangent to the nominal HA circle.

During HA, a nominal bank angle is commanded which will produce the desired turn radius. The bank command is not modulated by range; however, the angle of attack command is computed according to the range remaining and does not require the vehicle to fly around the nominal HA circle. Thus, when the energy is low, the guidance allows the vehicle to take a shorter route instead of forcing it to fly the nominal HA circle. The HA phase is terminated and the FA phase begun when either of the following situations is satisfied: the vehicle is headed toward the origin of the final approach glideslope, or the energy drops to the nominal value required for the final approach. Any errors in heading or energy which exist at this point are removed during the FA phase.

During the final approach, the guidance commands are a function of the vehicle's position and closure rates relative to the glideslope and localizer. The range energy relation used in preceeding flight phases is no longer employed.

TRANSITION CONTROL

The terminal guidance system can effectively control the Orbiter through transition from the back to the front side of the L/D curve. The transition will occur simultaneously with either the energy dissipation or the acquisition phase depending upon guidance requirements. The lateral guidance equations are unchanged for transition. Equations (1) and (2) are the longitudinal guidance commands for the energy dissipation and acquisition phase respectively:

$$\alpha_{com} = \alpha_{nom} + K_D \left[\frac{\dot{Z}}{\dot{Z}_{nom}} - 1\right] \tag{1}$$

$$\alpha_{com} = \alpha_{nom} + K_\alpha \Delta R + \left[K_D \quad \frac{\dot{Z}}{\dot{Z}_{nom}} - 1\right] \tag{2}$$

Both commands are limited between α_{min} and α_{max}. K_α and K_D are gains, ΔR is a normalized range error, $\dot{Z}_{NOM}$ is the equilibrium glide sink rate and $\dot{Z}$ the actual sink rate. α_{NOM} is the nominal angle of attack and is on the front side of the L/D curve. K_α is nominally equal to +1.65 and K_D to +1.0. If the upper limit (α_{MAX}) is removed and the gain K_D increased to large values (6), it will effectively limit the rate at which α changes from the pretransition value to the post-transition value (approximately α_{NOM}). Limiting α in turn limits the peak dynamic pressure. Although the damping command dominates the longitudinal guidance during transition small range adjustements can be made through the ΔR term.

Range Estimation - Estimated range is required during the ED, AC and HA phases. It is used to determine when to terminate the ED phase and for longitudinal guidance during the AC and HA phases. The total range is composed of three components which are range to be flown during acquisition (R_{AC}), heading alignment (R_{HA}) and final approach (R_{FA}). During the ED and AC the total range (R) is computed to be:

$$R = R_{AC} + R_{HA} + R_{FA}$$

As long as R is less than the vehicle's nominal range capability (R_N) the guidance remains in the ED phase. When R equals or exceeds R_N the AC phase is initiated. During AC, R is compared with R_N to provide the longitudinal guidance. During

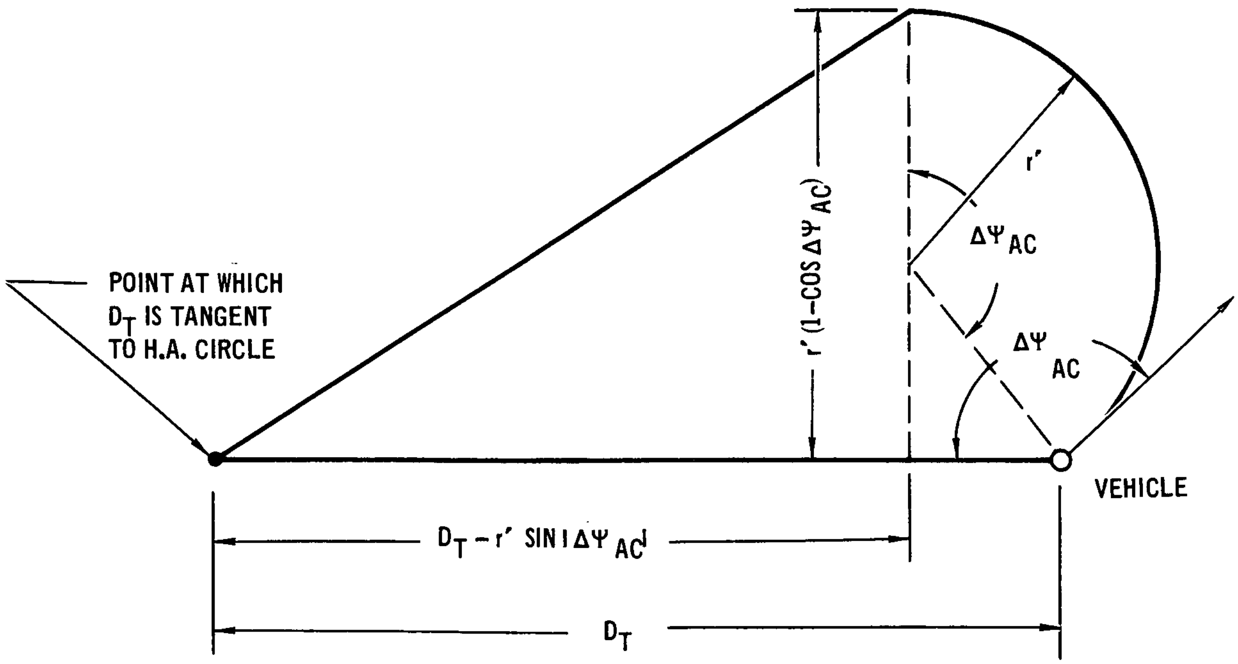
HA, the range becomes, $R = R_{HA} + R_{FA}$, and is compared with R_N for angle of attack modulation.

When the Mach number is less than 1.2, R_{AC} is computed from the geometry of Figure 4.3-41. This figure contains a number of approximations, but experience has shown that it provides satisfactory estimates of the actual range flown. D_T and $\Delta\psi_{AC}$ are computed from the vehicle position and heading. A turn radius r' is estimated based on the vehicle's instantaneous velocity and a 40 degree bank angle. 40 degrees is the maximum command allowed which is reached when $\Delta\psi_{AC}$ exceeds 23 degrees. From the geometry of Figure 4.3-41, R_{AC} is computed to be:

$$R_{AC} = r'\left[1.1\left|\Delta\psi_{AC}\right| + \sqrt{\left[\frac{DT}{r'} - \sin\left|\Delta\psi_{AC}\right|\right]^2 + \left[1 - \cos\Delta\psi_{AC}\right]^2}\,\right]$$

The constant (1.1) allows for the higher drag during a turn. In effect this says that the range which must be flown during a 40 degree bank is equivalent (from energy standpoint) to a level flight range which is 10 percent greater. Although this constant is a function of the vehicle's aerodynamic characteristics, it is not critical and is only included to refine the range estimate.

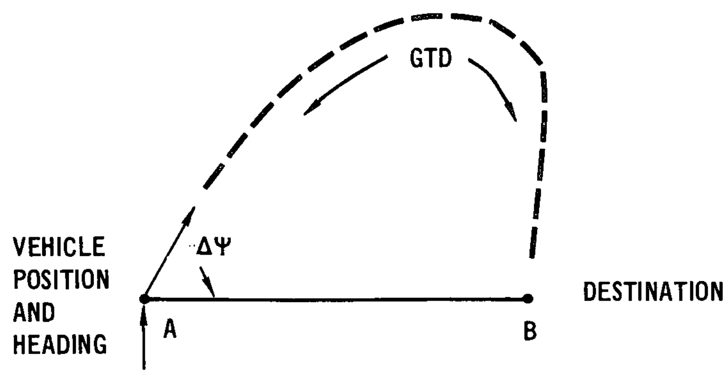
When the flight Mach number exceeds 1.2, the procedure which is followed to determine the total estimated GTD is illustrated in Figure 4.3-42. Given an initial position (A), velocity (V) and heading error $\Delta\psi$, a new position (A1) is computed. This is the position the vehicle will occupy after turning through an angle of $\Delta\psi$. The GTD between A and A1 is computed in addition to the velocity V1 and the new heading error $\Delta\psi$ 1. The process is now repeated to arrive at point A2 with corresponding velocity V2. This process can be repeated as many times as desired. The present program stops the process at point A2 and uses the straight line distance from A2 to point B. This technique has given the necessary accuracy in all cases studied to date.



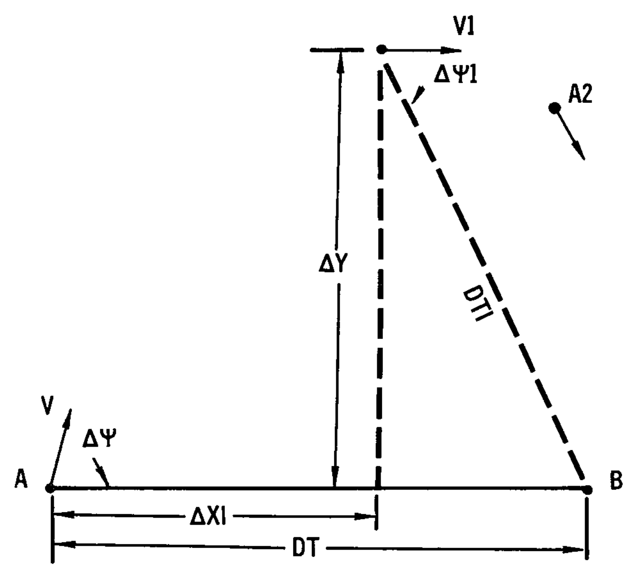
GEOMETRY FOR ESTIMATING ACQUISITION PHASE RANGE

$M \leq 1.2$

Figure 4.3–41



Range Estimation Procedure



GEOMETRY OF RANGE ESTIMATION PROBLEM

Figure 4.3–42

Equations 3 through 9 were derived in Reference F and are used to calculate the estimated range during acquisition as shown in Figure 4.3-41.

$$t = V|\Delta\psi| / (K_\psi + K_V(V)^{1/2}|\Delta\psi|/2) \tag{3}$$

$$GTD1 = Vt - \frac{K_V}{2} V^{1/2} t^2 + K_V^2 t^3/12 \tag{4}$$

$$\Delta X1 = \frac{V^2}{K\psi(1+(\frac{Kp}{a})^2)} \left[\frac{Kp}{a} (COS|\Delta\psi| - e^{\frac{-Kp}{\alpha}|\Delta\psi|}) + SIN|\Delta\psi|\right] \tag{5}$$

$$\Delta\psi 1 = \frac{V^2}{K\psi\,(1+\left(\frac{Kp}{a}\right)^2)} \left[e^{\frac{-Kp}{\alpha}|\Delta\psi|} + \frac{Kp}{\alpha} SIN|\Delta\psi| - COS|\Delta\psi|\right] \tag{6}$$

$$|\Delta\psi_1| = |ATN\ (\frac{\Delta Y1}{D_t - \Delta X1})| \tag{7}$$

$$Dt1 = \left[(Dt - \Delta X1)^2 + \Delta Y1^2\right]^{1/2} \tag{8}$$

$$V1 = V - K_V(V)^{1/2}t + (K_V t/2)^2 \tag{9}$$

With $\Delta\psi 1$ and V1 the quantities GTD2, $\Delta X2$ and $\Delta Y2$ can be computed. From these the total ground track estimate is obtained.

$$R_{AC} = GTD1 + GTD2 + \left[(D_t 1 - \Delta X2)^2 + \Delta Y2^2\right]^{1/2}$$

$R_{HA} + R_{FA}$ is computed in two ways. During the ED and AC phases it is computed as:

$$R_{HA} + R_{FA} = 1.06\ r_T \left|\Delta\psi_{HA}\right| + 50{,}000.$$

The constant (1.06) is equivalent to the constant (1.1) in the R_{AC} equation and is smaller because the average bank angle during HA is less than the 40 degrees bank assumed previously.

The nominal range allotted for the FA phase is 50,000 feet. The above equation assumes that the vehicle will follow the nominal HA and FA path.

During HA the estimated range is:

$$R_{HA} + R_{FA} = r_T \left(1.06 |\psi - \sin|\psi| \right) + X$$

This expression assumes that instead of following the nominal HA path the vehicle will make the HA turn from its present position. This expression does not constrain the vehicle to fly around the nominal heading alignment circle.

MACH DEPENDENT FUNCTIONS

Mach dependent aerodynamics necessitate specifying α_{MAX}, α_{NOM} and α_{MIN} as functions of Mach No. Thus, α_{MAX} is determined explicitly, α_{MIN} limits the maximum dynamic pressure, and α_{NOM} is a matter of choice. α_{NOM} is the angle of attack at which the L/D ratio is half way between the L/D ratios at α_{MIN} and α_{MAX}. The following table contains the values α_{MIN}, α_{NOM} and α_{MAX}.

Mach No.	α_{MIN} (deg)	α_{NOM} (deg)	α_{MAX} (deg)
0.25	0.6	2.2	7.0
0.8	0.8	2.2	7.0
1.1	0.6	2.4	8.0
2.0	2.5	3.6	7.0

The program uses linear interpolation between points and assumes zero slope outside the range of the table. Wings-level computer runs at α_{NOM} and α_{MAX} determine the nominal and maximum range vs energy functions R_N and R_M. These functions are given in the following table exactly as programed.

The table of R_N vs E is used in two ways. First, the table is entered with the vehicle's computed energy to determine the nominal range capability (R_N) and second, the table is entered with estimated range values to determine at what energy phase switching should occur. The R_M table is used only to approximate the vehicle's maximum range capability.

$E(ft/sec)^2$	$R_N(ft)$
$.261 \times 10^6$	0
2.480	1.746×10^5
2.868	2.032
3.135	2.205
3.448	2.387
3.810	2.579
4.268	2.785
4.819	3.014
9.500	4.800
25.000×10^6	10.75×10^5

$E(ft/sec)^2$	$R_M(ft)$
$.1263 \times 10^6$	0
3.513	3.490×10^5
4.017	3.974
4.336	4.237
4.722	4.518
5.161	4.817
5.721	5.150
7.222	5.977
9.507	7.083
25.00×10^6	14.500×10^5

Guidance Commands - The guidance commands used during the four phases of a typical flight are summarized in Figure 4.3-43. During ED the angle of attack command consists of only a nominal command (α_{NOM}) plus a phugoid damping command (α_{DAMP}). α_{NOM} is a function of bank angle and is designed to maintain a constant vertical lift component. The damping command is obtained by comparing the sink rate $\dot{Z}$ with the nominal sink rate ($\dot{Z}_{NOM}$) during equilibrium glide.

$$\alpha_{DAMP} = (\dot{Z}/\dot{Z}_{NOM}) - 1.0$$

The lateral command during ED is proportional to the change in heading ($\Delta\ \psi_{ED}$) needed to direct the vehicle toward the ED circle. The constant $K\phi_{ED}$ together with all other constants in the guidance command equations was determined initially through a combination of past experience and simplified stability analysis. These constants were then adjusted to obtain the desired response during simulated flights. None of the constants are critical, and a change of 25% in any of them has little effect on system performance. The heading angle error $\Delta\psi_{ED}$ is computed as illustrated in Figure 4.3-44, where ψ_{ED} is the desired vehicle heading and ψ the actual vehicle heading. Note that ψ_{ED} is composed of two terms. The first term gives the heading (ψ_c) of a vector from the center of the ED circle to the vehicle and the second term adds a heading term proportional to the square of (R_{ED}/R_{RDN}) where R_{EDN} is the radius of the ED circle. The sign of the second term is determined by the sign of ψ_c, so that the vehicle acquires the energy dissipation circle with a minimum heading change.

During AC the longitudinal command consists of the nominal and damping commands plus a term proportional to the difference between estimated and nominal range;

$$K_\alpha \frac{(R - R_N)}{(R_M - R_N)}$$

FLIGHT PHASE	LONGITUDINAL COMMAND (α_c)	LATERAL COMMAND (ϕ_c)
ENERGY DISSIPATION	$\alpha_{NOM} + \alpha_{DAMP}$	$K_{\phi_{ED}} \Delta\psi_{ED}$
ACQUISITION	$\alpha_{NOM} + \alpha_{DAMP} + K_\alpha \left[\frac{R-R_N}{R_M-R_N}\right]$	$K_{\phi_{AC}} \Delta\psi_{AC}$
HEADING ALIGNMENT	$\alpha_{NOM} + \alpha_{DAMP} + K_\alpha \left[\frac{R-R_N}{R_M-R_N}\right]$	$\text{ATN} \left[\frac{V^2 \cos\gamma}{g\, r_T}\right] \text{SIGN (Y)}$
FINAL APPROACH	$\alpha_{NOM} + K_H h_{error} + K_{\dot{H}} \dot{h}_{error}$	$-[.045Y + 0.5\dot{Y}]$

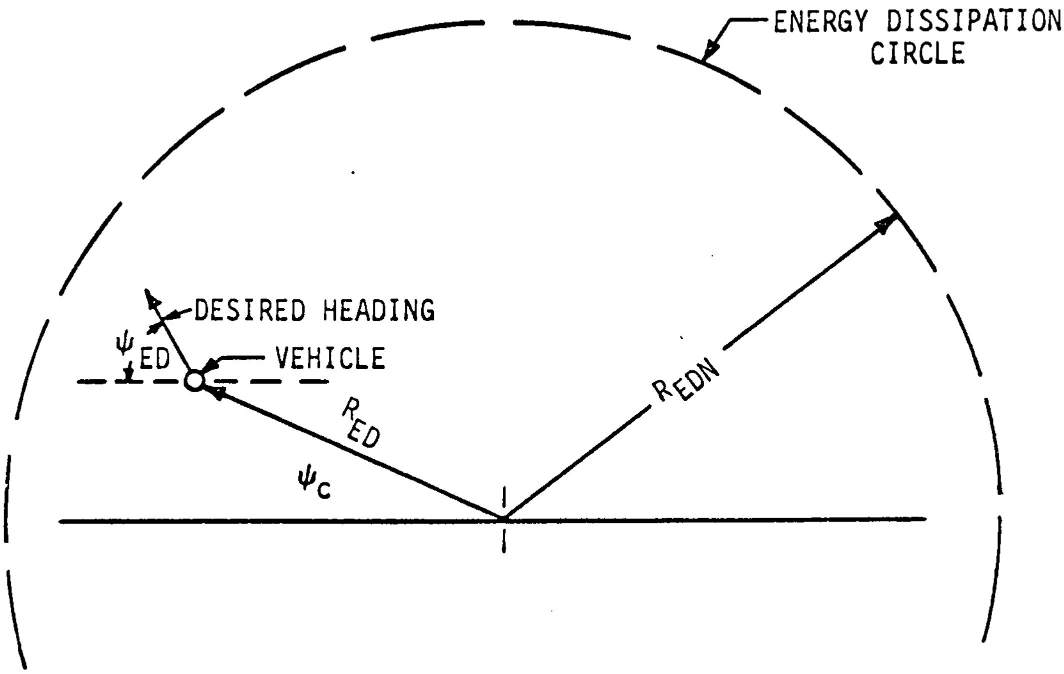
AUTOPILOT COMMANDS

$$\dot{\theta}_c = (\alpha - \alpha_c)k$$

$$\dot{\phi}_c = .5(\phi - \phi_c)$$

GUIDANCE COMMANDS

Figure 4.3-43



$$\psi_{ED} = \psi_c + 90 \underbrace{\left(\frac{R_{ED}}{R_{EDN}}\right)^2}_{\text{LIMITED TO VALUES BETWEEN } \pm 180°} [SGN\ (\dot{\psi}_c)]$$

$$\Delta\psi_{ED} = \psi_{ED} - \psi$$

COMPUTATION OF DESIRED HEADING DURING ENERGY DISSIPATION

Figure 4.3–44

K_α is a constant, R the estimated ground track range to go, R_N and R_M the ranges which are possible by flying the nominal and maximul L/D respectively. The derivation of R_N and R_M is given in Reference E. The lateral command is proportional to $\Delta\psi_{AC}$, the angle between the vehicle heading and a vector tangent to the HA circle. An illustration of $\Delta\psi_{AC}$ is presented in Figure 4.3-41.

During HA the longitudinal command equation is unchanged from the previous phase; however, the method of computing R, the estimated ground track to go, is changed, as discussed previously. The magnitude of the bank command is:

$$|\phi_c| = \text{ARCTAN} \frac{V^2 \cos\gamma}{g\ r_T}$$

which gives a turn radius very nearly equal to the nominal desired turn radius r_T. The sign of the bank command is determined by the sign of Y at the beginning of the HA phase.

During FA the longitudinal command consists of the nominal command plus commands proportional to the vertical error between the vehicle and the desired glideslope (h_{error}) and the rate at which that error is changing (h_{error}). The vertical error rate command performs the same functions as α_{DAMP} in previous flight phases. The lateral command is proportional to the horizontal distance from the glideslope (Y) and its rate of change (Y). The logic employed in determining the vertical position and rate error signals is detailed in Figure 4.3-45. When the vehicle approaches to within 200 feet of the shallow 2.75 degree glideslope, the flight path angle command signal, γ_{HOLD}, switches which initiates the flare maneuver by increasing the error rate signal, h_{error}. This system provided final approach guidance commands for the steep approach, high energy flare and float, to the pilot or the autopilot. Guidance commands for the landing flare are not implemented.

$$h_{error} = h - h_{c1} \text{ when } h_{c1} \geq h_{c2}$$

$$h_{error} = h - h_{c2} \text{ when } h_{c1} \leq h_{c2}$$

$$\gamma_{hold} = -11.1° \text{ when } h_{c1} \geq h_{c2} + 200 \text{ ft}$$

$$\gamma_{hold} = -2.75° \text{ when } h_{c1} \leq h_{c2} + 200 \text{ ft}$$

$$\dot{h}_{error} = V \sin(\gamma - \gamma_{hold})$$

Flare command occurs 200 feet above shallow glideslope.

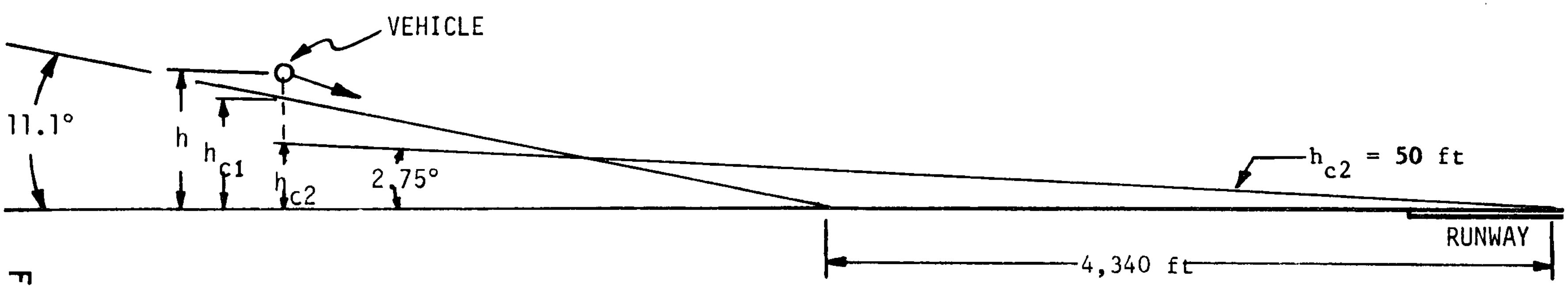


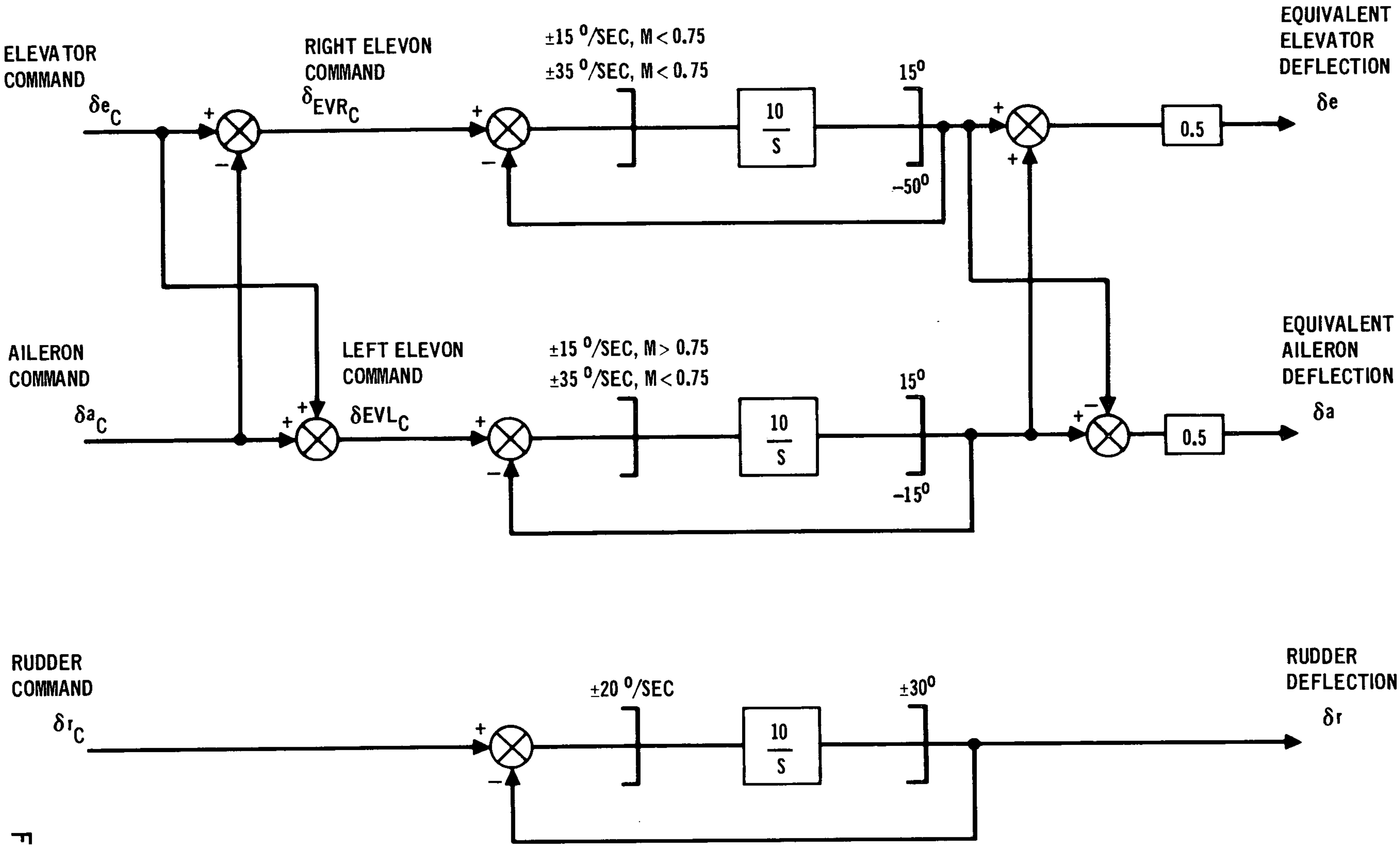
Figure 4.3-45

LANDING GEOMETRY AND GUIDANCE ERROR CALCULATIONS

4.3.2.4 Attitude Control System - The primary function of the reentry and terminal control systems is to provide angle of attack and bank angle commands to the crew and the respective guidance systems. The Shuttle aerodynamics described in section 4.3.2.1 were used in arriving at the control system configuration. Figure 4.3-46 illustrates the aero surface actuator model.

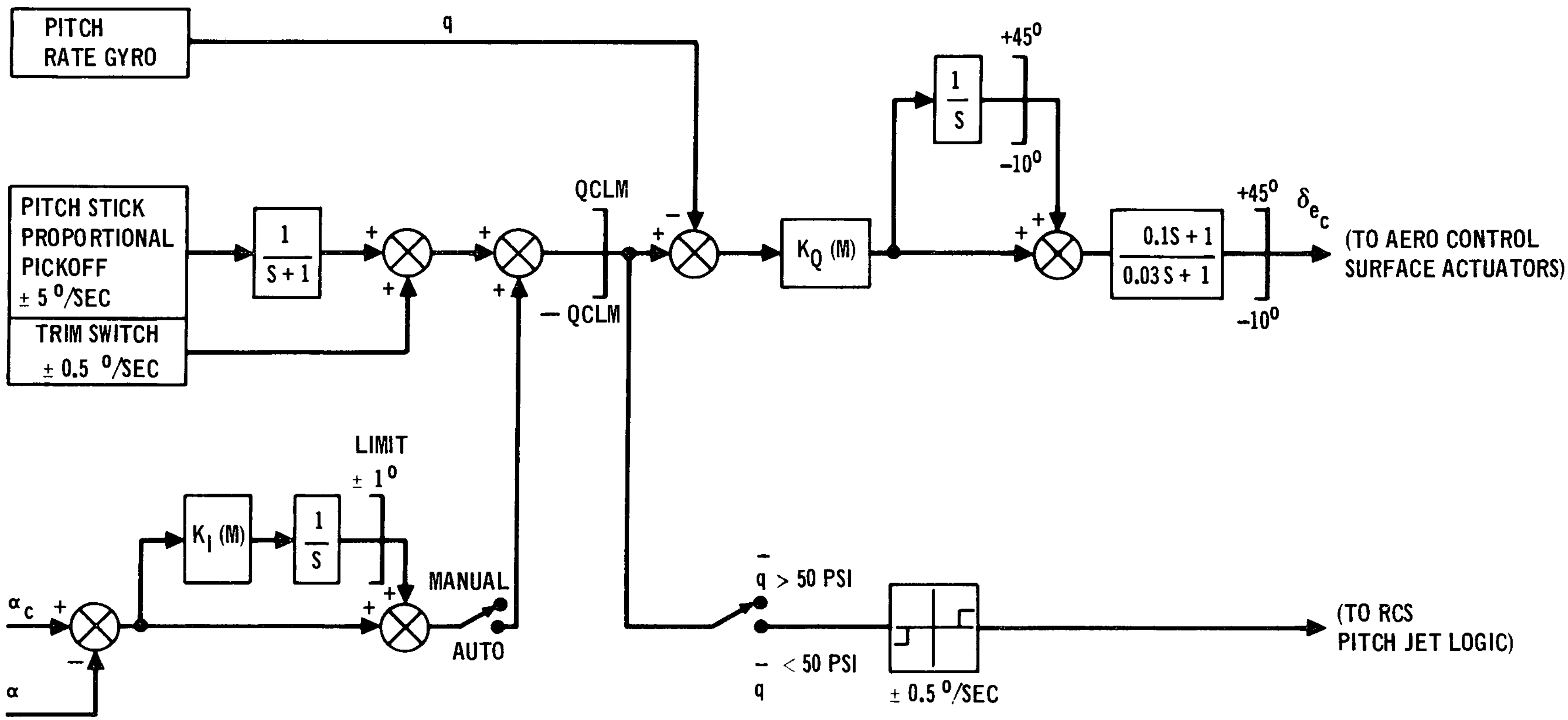
4.3.2.4.1 Entry Attitude Control - Functional block diagrams of the reentry longitudinal and lateral-directional control systems are presented in Figures 4.3-47 and 4.3-48. A blended elevon/reaction control system is employed for pitch axis control. Since the center vertical is not effective during the hypersonic portion of reentry, reaction control is always required in the directional channel. Differentially deflected elevons can provide aerodynamic roll control, but propellant penalties may be incurred due to adverse aileron yaw ($C_{n_{\delta A}}$) and potential heating problems can occur because of the larger elevon deflections required to provide both pitch and roll control. Therefore, all reaction jet control is selected for the lateral-directional channel. Although it is not shown on the block diagram, a three-axis attitude hold mode is employed for attitude control during the exoatmospheric phase of reentry subsequent to deorbit and prior to atmospheric encounter (0.05 g's). The reentry propellant requirement, including the effects of wind shear and wind gusts, lateral asymmetries, and uncertainties in vehicle aerodynamic and physical characteristics is 2000 pounds.

The pitch axis control system is used from reentry through landing. The blended aerodynamic/reaction control system operates on the principle that the reaction jets fire whenever the control system error signal exceeds a predetermined deadband. Simulation results show elevons provide adequate pitch control at a dynamic pressure of approximately 50 PSF, and therefore the reaction jets are deactivated at this pressure.



AERO CONTROL SURFACE ACTUATORS

Figure 4.3-46



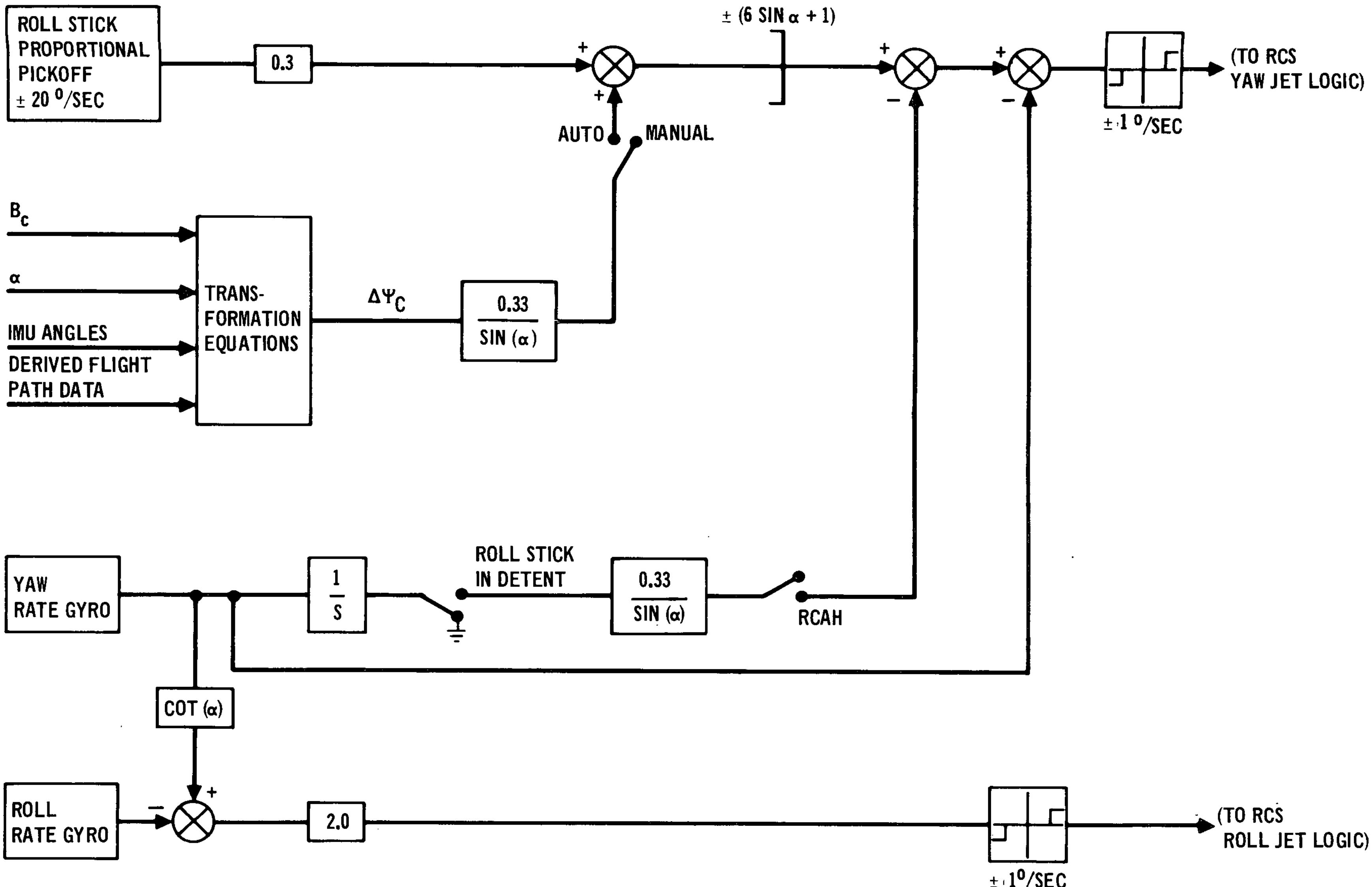
$$K_I = \begin{cases} 0.1, & M > 2 \\ 1 & M < 2 \end{cases}$$

$$K_Q = \begin{cases} 5, & M > 16 \\ 11.667 - 0.417M, & 4 < M < 16 \\ 3.75\,M - 5, & 2 < M < 4 \\ 2.5, & 1 < M < 2 \\ 1, & M < 1 \end{cases}$$

$$QCLM = \begin{cases} \text{MANUAL} & \\ 5, & M > 1 \\ 10, & M < 1 \\ \text{AUTO} & \\ 0.5, & 2 < M < 7 \\ 5, & M < 2 \end{cases}$$

Figure 4.3-47

LONGITUDINAL CONTROL SYSTEM



ENTRY LATERAL – DIRECTIONAL CONTROL SYSTEM

Yaw Axis Control Scheme

Figure 4.3-48

Three control modes are provided--an automatic angle-of-attack control mode, a manual rate command mode, and a manual rate command/attitude hold (RCAH) mode. In the automatic mode, the control system provides the angle-of-attack orientation commanded by the reentry guidance system. The attitude command is rate-limited to provide pitch maneuver rates of ± 5 degrees per second, and a small amount of integral compensation is employed to eliminate "droop" in the system. In the manual rate command mode, the pilot commands a pitch rate proportional to the pitch stick deflection until the desired angle of attack is attained. The stick force then is removed and an automatic trim function tends to hold a constant control surface deflection. This trim feature stems from the use of a forward-loop integration in the system. A lead-lag compensation network is included to achieve the desired short-period frequency and damping characteristics required to satisfy handling qualities criteria. The RCAH mode is similar to the rate command mode except that it provides an attitude hold function to maintain the desired angle of attack when the pitch stick is in the detent position. The RCAH mode is used only during the hypersonic flight regime.

The entry aerodynamic configuration is statically unstable in the directional axis during hypersonic flight. However, the vehicle is dynamically stable at the angles of attack flown during reentry because of the stabilizing influence of positive dihedral. The following expression for the airframe Dutch roll natural frequency illustrates how positive dihedral can compensate for a static directional instability.

$$\omega_D^2 = \frac{qsb}{I_Z}\left(C_{n_\beta} \cos \alpha - \frac{I_Z}{I_X} C_{\ell_\beta} \sin \alpha\right)$$

The positive dihedral provides a stabilizing roll moment proportional to the angle of sideslip which tends to roll the vehicle in a direction that reduces the angle of sideslip. However, in order to take advantage of the stabilizing effects of positive dihedral, vehicle roll attitude cannot be constrained too tightly. These considerations led to the design of the "yaw" control system which has been selected for lateral-directional control.

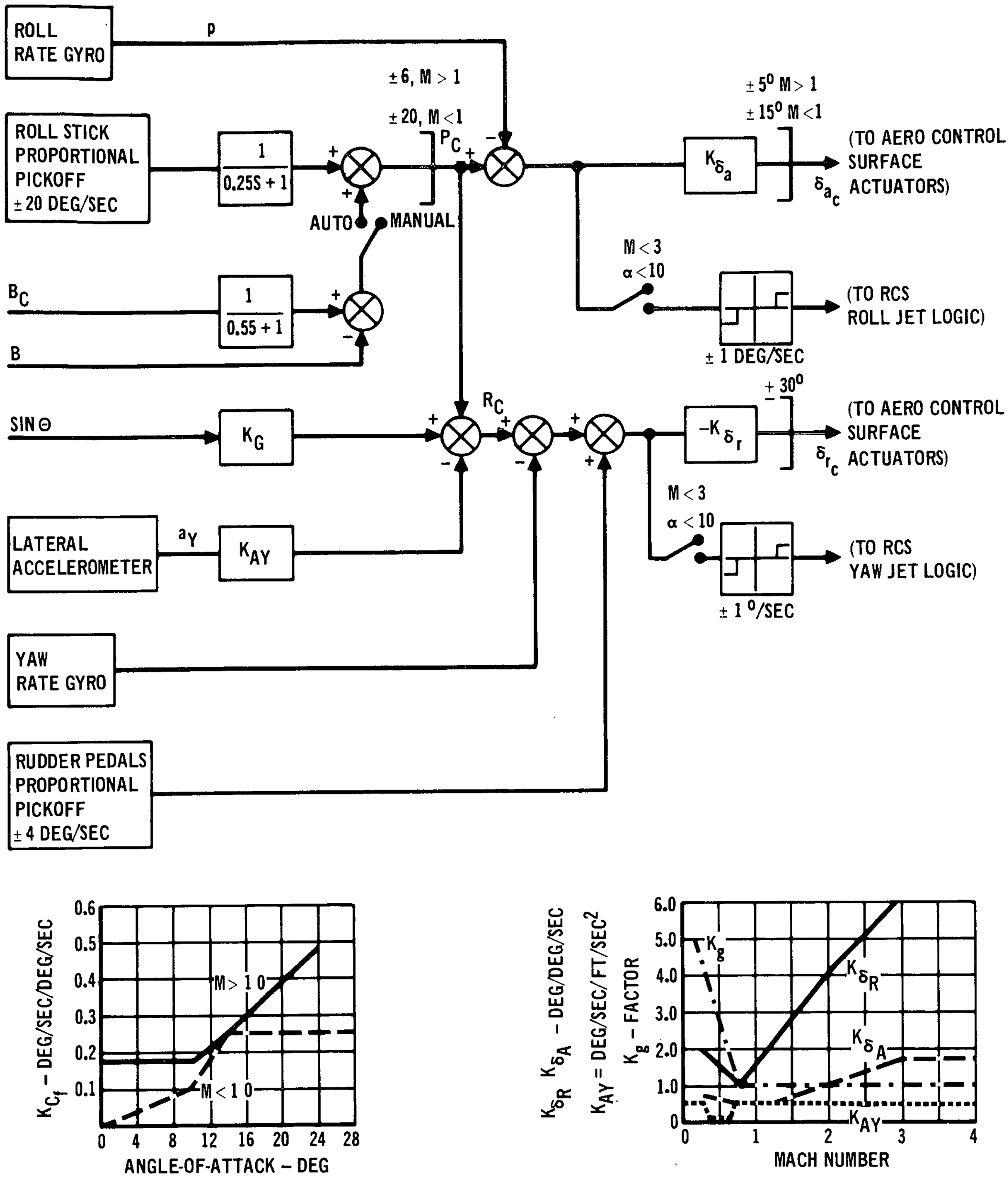
The lateral-directional reentry control system provides an automatic control mode and a manual control mode. In the automatic mode, the attitude error signal is fed into the yaw axis control logic, and a yaw-to-roll rate cross-feed is employed for roll rate coordination during maneuvers. Roll rate feedback and yaw rate feedback provide damping. The attitude error signal defines the angle through which the vehicle must be rotated about the body yaw axis to achieve the desired bank angle. It is computed using the commanded values of bank angle and angle of attack, IRU angles, and derived flight path data. The attitude error is rate-limited to provide a six degree per second maneuver rate about the velocity vector throughout the angle-of-attack range flown during reentry. The α-dependent attitude error gain established a constant ± 3 degree equivalent bank angle deadband. All attitude and rate deadbands are chosen to minimize propellant consumption. Note that angle-of-sideslip (β) feedback or lateral acceleration feedback is not required with the yaw control system. This is one of the attractive features of this control scheme since the capability of obtaining a sufficiently accurate measurement of β in the hypersonic flight regime is highly questionable.

A rate command/attitude hold (RCAH) mode is used for manual control. The computed attitude error signal that is used for automatic control is also displayed on the ADI flight director needles. Using the roll stick, the pilot commands a yaw rate that is proportional to roll stick deflection in order to null the displayed attitude error. When the attitude error is nulled, stick force is removed and the control system maintains current vehicle attitude.

4.3.2.4.2 <u>Terminal Area Attitude Control</u> - The terminal area attitude control system is used throughout the transition to landing portion of the flight. This system employs the same pitch control system used during the reentry phase. There is not a requirement to employ the pitch axis blended reaction/aerodynamic control function as sufficient pitch control power is obtained using the elevons alone.

The lateral directional control system for the transition and subsequent flight phases is shown in Figure 4.3-49. Until the Mach number decreases to 3.0 and the angle of attack decreases to 10.0 degrees, blended reaction/aerodynamic control is employed in both the roll and yaw axes. Thereafter, only aerodynamic control is employed. In the manual mode, roll stick deflections command a roll rate proportional to the stick force applied. The signal is passed through 0.5 second time constant filter which, along with the roll rate feedback, provides shaping to obtain the desired roll time constant, T_R, and reduced roll elevon rate requirements.

The lateral directional stabilization system is more complex than the pitch axis system. Negative values of Cn_β, roll-yaw coupling, control coupling and basic configuration features all contribute to this greater complexity. Rudder channel feedback parameters include yaw rate, lateral acceleration, body roll attitude and a roll-yaw crossfeed. Yaw rate feedback provides Dutch roll damping, and lateral acceleration provides directional stiffness. The crossfeed, along with the lateral acceleration loop, eliminates roll reversal for conditions of negative Cn_β and/or $Cn_{\delta a}$. It also improves roll performance at high angles of attack even if Cn_β is positive. The purpose of the roll attitude feedback is to act as a β damper to prevent rapid build up of an adverse sideslip due to banking.



TERMINAL AREA LATERAL-DIRECTIONAL CONTROL SYSTEM

Figure 4.3–49

A roll attitude loop is provided for automatic bank control. Automatic turn coordination deletes the requirement for primary control inputs into the yaw axis.

Control system gains are programmed as a function of Mach number and angle-of-attack as given in Figure 4.3-49. The crossfeed gain, K_{cf}, is varied primarily as a function of angle-of-attack, while the others are varied as functions of Mach number.

4.3.3 HFSS Hybrid Computer System - The HFSS Hybrid Computer System is comprised of two digital computers (a CDC6600 and a Varian 620I) with peripheral equipment, an Information Displays, Inc. (Computer Graphics System (IDIIOM), and a linkage system for analog-to-digital and digital-to-analog conversions. Each of these components is described below.

The CDC6600 is a large, general purpose, multiprocessor, multiprogrammed digital computer capable of servicing two or more independent hybrid problems simultaneously. The 6600 can also control and set-up the analog computers and provide alph-numeric CRT displays to operators and programmers. It has a central processor with 60 bit word, 98K memory, ten peripheral processors with 12 bit word, and 4K each of memory, and major and minor cycles of one microsecond and 100 nanoseconds, respectively. Other features include:

12 12-bit I/O channels
(2 megacycle character transfer rate)

2 Line printers

1 Card reader

1 Dual CRT console

3 Magnetic tape units
(200, 556, 800 BPI)

6 Remote CRT consoles

1 Disk file with 75,000,000 character capacity

2 Remote terminal multiplexors

The Varian 620I has 16 bit word (plus memory parity), 12K memory with a 1.8 microsecond cycle time. It uses fixed point arithmetic and 8 external interrupts. Other features include:

1 Fully buffered data channel

1 10 character/sec. paper tape station

1 Magnetic tape unit (556 and 880 BPI)

1 6600 to 620I channel coupler

The IDIIOM is a display and information input-output system with a programmable memory. It enables the user to work directly with a wide range of stored information and data processing operations. IDIIOM functions as an output terminal for the CDC6600, and it will produce up to six separate CRT displays for cockpit use. The principal components of the system are given below:

3 21 inch CRT display screens

1 Interactive light pen

1 Function keyboard (32 keys)

1 Alphanumeric Keyboard and printer

The HFSS linkage system provides the electronic signal conditioning required for communication between the HFSS and the control computer complex. The computer interface consists of a control unit, I/O data register modules (A/D, D/A, and discrete digital channels), and a buffer/encoder section. The linkage requirements for the HFSS are:

16 A/D channels

88 D/A channels

384 Discrete input

384 Discrete output

4.4 Test Plan

4.4.1 Initial Conditions - The twelve conditions which have been selected for initializing the simulator are presented in Figure 4.4-1.

4.4.2 Run Matrix - The run matrix for evaluating the functional requirements of the flight crew interface during the Return Sequence is presented in Figure 4.4-2.

4.4.3 Crew Procedures - In general, the crew procedures will be based upon the timeline in Figure 3.2-4. Initial runs will reflect part task crew procedures to verify all areas of D&C requirements and mechanization. The Run Matrix of Figure 4.4-2 is designed for a gradual build-up of experience and procedures development.

4.5 Results - The crew systems interface will be evaluated using qualitative and quantitative data pertinent to following items:

- CRT calling procedures
- CRT displays
- electromechanical displays and controls
- display locations
- contingency display requirements
- command/control capability for normal and contingency operation
- mission timelines
- flight profile data

Some qualitative data will be in the form of pilot ratings based on the 10 point scale illustrated in Figure 4.5-1. Additional qualitative data will be evaluation forms, such as the forms in Figure 4.5-2 in which the pilots will register pilot rating and comments on the displays and controls.

IC NO.	ALTITUDE	CONDITION	MISSION PHASE
1	270 NM	55^0 INCLINATION, CIRCULAR ORBIT	ORBIT
2	300 KFT	ATMOSPHERE PENETRATION, CENTER OF FOOTPRINT, 1100 NM CROSS RANGE	ENTRY
3	300 KFT	ATMOSPHERE PENETRATION, CENTER OF FOOTPRINT, NO CROSS RANGE	ENTRY
4	300 KFT	ATMOSPHERE PENETRATION, HEEL OF FOOTPRINT, 600 NM CROSS RANGE	ENTRY
5	220 KFT	TEMPERATURE CONSTRAINT ENCOUNTER	ENTRY
6	150 KFT	PRE-TRANSITION	ENTRY
7	75 KFT	POST-TRANSITION, NOMINAL ENERGY	TERMINAL AREA
8	75 KFT	POST-TRANSITION, HIGH ENERGY	TERMINAL AREA
9	75 KFT	POST-TRANSITION, LOW ENERGY	TERMINAL AREA
10	10 KFT	FINAL APPROACH INITIATION, NOMINAL	FINAL APPROACH
11	10 KFT	FINAL APPROACH INITIATION, MAXIMUM ALTITUDE ERROR	FINAL APPROACH
12	10 KFT	FINAL APPROACH INITIATION, MAXIMUM HORIZONTAL ERROR	FINAL APPROACH

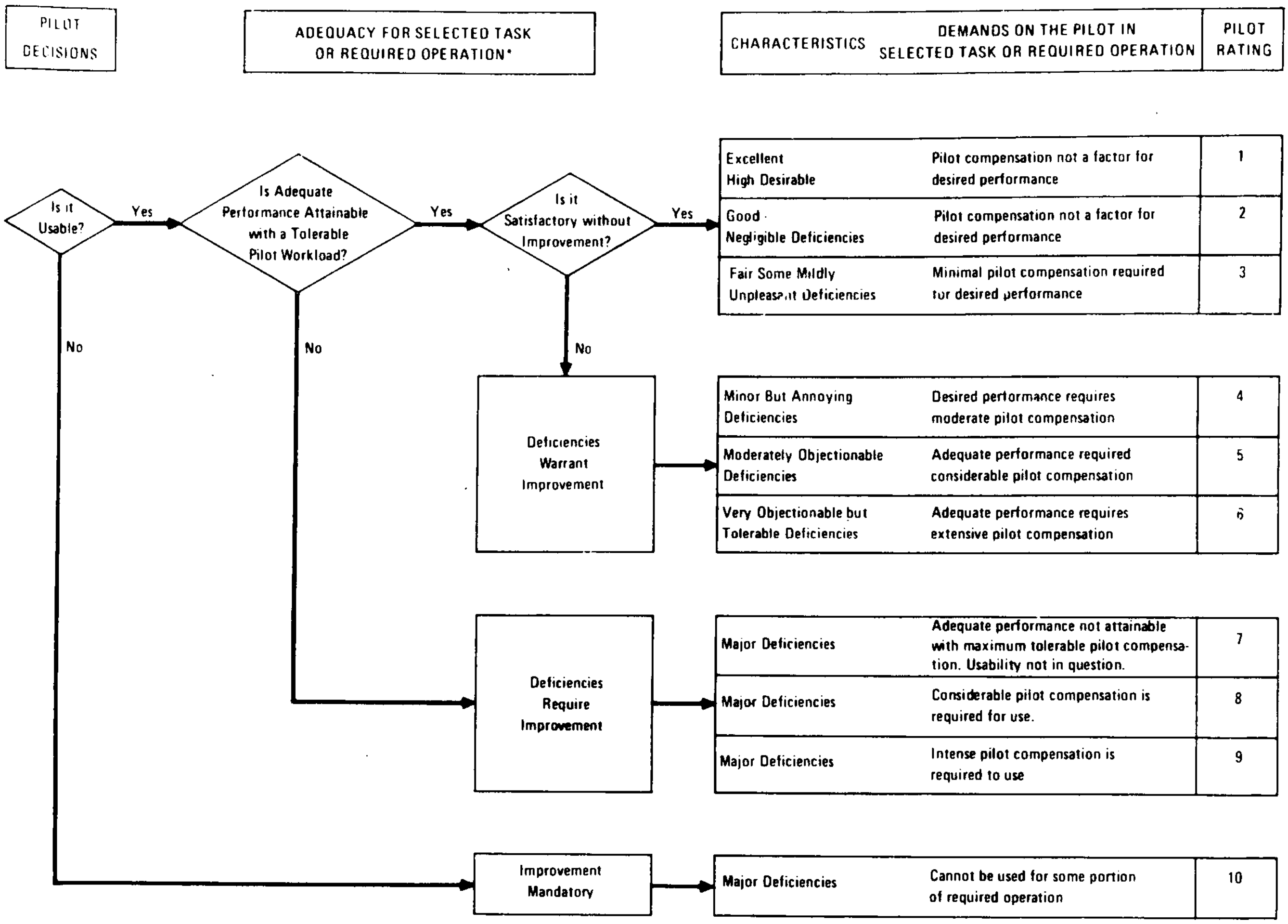
INITIAL CONDITIONS

Figure 4.4-1

SIMULATION TEST OBJECTIVES	RUN DURATION (MIN)	INITIAL CONDITIONS	MDAC PILOT		NASA PILOT	
			LEARNING RUNS	DATA RUNS	LEARNING RUNS	DATA RUNS
EVALUATION OF ENTRY D&C CAPABILITY FOR FIRST DIP MANEUVERS, TEMPERATURE CONTROL, FOOT-PRINT ALIGNMENT AND STEERING TO HIGH KEY	15	2, 3, 4, 5	1	3	1	3
EVALUATION OF TERMINAL D&C CAPABILITY FOR TRANSITION INITIATION/CONTROL, TERMINAL AREA STEERING AND ENERGY MANAGEMENT	10	6, 7, 8, 9	1	3	1	3
EVALUATION OF FINAL APPROACH D&C FOR FLIGHT CREW ASSESSMENT OF OVERALL FLIGHT PERFORM-ANCE	5	10, 11, 12	1	3	1	3
EVALUATION OF REQUIREMENTS FOR GRAPHICS DIS-PLAYS DURING ENTRY PHASE	15	2, 3, 4, 5		3		3
EVALUATION OF REQUIREMENTS FOR GRAPHICS DIS-PLAYS DURING TRANSITION AND TERMINAL PHASE	10	6, 7, 8, 9		3		3
ALL-UP ENTRY TO LANDING DATA RUNS WITH OFF NOMINAL CONDITIONS AND NAVIGATION ERRORS	50	2, 3, 4, 5		4		4
EVALUATION OF PLATFORM ALIGNMENT D&C	5	1	1	2	1	2
EVALUATION OF NAVIGATION D&C	5	1	1	2	1	2
EVALUATION OF D&C CAPABILITIES FOR SELECTING LANDING SITE, ENTRY CONDITIONS, EVALUATING RETRO TIME. ALSO, EVALUATION OF D&C FOR ORBITAL MANEUVERS (i.e. ROTATION AND TRANSLA-TION)	10	1	1	3	1	3
ALL-UP DEORBIT DATA RUNS TO DEMONSTRATE FLIGHT CREW DATA MANAGEMENT REQUIREMENTS	15	1		3		3
ALL-UP DEORBIT THROUGH LANDING DOCUMENTA-TION OF RESULTS	90	1		1		1
			10 HOURS TOTAL		10 HOURS TOTAL	

RUN MATRIX

Figure 4.4–2



*Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions

SYSTEM RATING SCALE

Figure 4.5–1

ITEM BEING RATED ____________________

THIS ITEM IS A. ________ TASK ________ PROCEDURE ________ DISPLAY

________ CONTROL ________ OTHER

CONSIDERATIONS: ____________________

NO:
DATE:
DATA ID:
REF:
PILOT:

☐ FLT TEST ☐ ENGINEER
☐ NASA ☐ OTHER

PILOT RATINGS (CK BOX)	COMMENTS:	CONFIGURATION INVESTIGATED AIRCRAFT:
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10		

PILOT RATING AND COMMENT SHEET

Figure 4.5–2

The CRT calling procedures will be evaluated through pilot comments corroborated by data records of keyboard operations. Specifically, accumulative time history of data dispatch instructions and OPS, PRO, "+", and "-" key strokes at each terminal will be recorded.

Evaluation of the CRT displays will consist of numberical pilot ratings and pilot evaluation forms. The evaluation form will contain an illustration of the display on which the pilot may indicate comments and recommended modifications. A time history of the display utilization at each terminal with information on ITEM, ENTER, and EXECUTE key strokes will be recorded to aid in the display evaluation process.

The electromechanical display and control evaluation will be based on pilot comment. Likewise comments on the overall crew station arrangement will be requested.

The command/control capability and display requirements for normal and contingency (backup) operation will be evaluated from pilot comments based on simulator runs with nominal and degradated display capability as indicated in the run schedule of Section 4.4.2.

The mission timelines will be evaluated based on the crew workload in the simulator environment.

Flight profile data, printed every 10 seconds, includes trajectory, attitude, guidance and control parameters. The variables are shown in the printout format in Figure 4.5-3. Definitions of these variables are presented in the List of Variables section of this report (section 4.2).

T	H	M	$\overset{\circ}{H}$	$\bar{q}$	L/D
R	V	γ	Φ	Θ	Ψ
V_N	V_E	V_D	A_X	A_Y	A_Z
W_N	W_E	W_D	L_A	M_A	N_A
p	q	r	L_T	M_T	N_T
Φ_P	Θ_P	Ψ_P	Φ_G	Θ_G	Ψ_G
B	α	β	Φ_N	Θ_N	Ψ_N
B_c	α_c	IMP	δa_c	δr_c	δe_c
p_c	q_c	r_c	δa	δr	δe

ENTRY FORMAT

MODE	CONST	HMINC	HMIN	TEMP	
RD	RC	RDTHK	RCTHK	RDTHKE	RCTHKE
LODVR	LODLR	DLODV	ROMIN	RDMAX	RCMAX
LODVC	LODLC	LODC			

TERMINAL AREA FORMAT

PHASE	E	X	Y	$\dot{X}$	$\dot{Y}$
R_{NOM}	R_{EST}	R_{MAX}	δ_{SB}	δ_{SB_C}	
HERR	DEV				

PRINTOUT FORMAT

Figure 4.5–3

5.0 REFERENCES

A. "Delta Wing Orbiter Simulation Aerodynamic Data Book," W. R. Edmiston, Memo No. SSPO-E241-534, dated 28 June 1971

B. "Shuttle Orbiter Reentry Guidance System," J. P. Carter, Memo No. E238-180, dated 6 May 1970

C. "High Cross Range Shuttle Orbiter Reentry Guidance," J. P. Carter, Memo No. E238-215, dated 8 September 1970

D. "Terminal Guidance," E. E. Stoner, Memo No. E238-182, dated 1 May 1970

E. "Spiral Descent Terminal Guidance," E. E. Stoner, Memo No. E238-199, dated 17 June 1970

F. "High Cross Range Orbiter Terminal Guidance," E. E. Stoner, Memo No. E238-245, dated 9 March 1971